Naval Command,
Control and Ocean
Surveillance Center RDT&E Division San Diego, CA
92152-5001

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Technical Document 2648
May 1994

Engineer's Refractive Effects Prediction System (EREPS)

Version 3.0

W. L. Patterson
C. P. Hattan
G. E. Lindem
R. A. Paulus
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ADMINISTRATIVE INFORMATION

This work was performed for the Office of Naval Research under accession number DN302217, program element 0602435N, project MPB4, subproject RO35T84.

NOTE: The EREPS 3.0 program floppy diskette supplied with this document has the same classification and distribution as the document.

Released by
R. A. Paulus, Head
Tropospheric Branch

Under authority of
J. H. Richter, Head
Ocean and Atmospheric
Sciences Division

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Contents

Before You Begin

The Engineer's Refractive Effects Prediction System (EREPS) User's Manual contains detailed information about the various EREPS programs.

EREPS is a system of individual stand-alone IBM/PC-compatible programs to aid an engineer in properly assessing electromagnetic (EM) propagation effects of the lower atmosphere on proposed radar, electronic warfare, or communication systems. The EREPS models account for effects from optical interference, diffraction, tropospheric scatter, refraction, evaporation and surface-based ducting, and water vapor absorption under horizontally homogeneous atmospheric conditions.

Typographical Conventions

Before you start using EREPS, it's important to understand the terms and typographical conventions used in the documentation. The following kinds of formatting in the text identify special information.

Formatting convention	Type of information
Triangular bullet (►)	Step-by-step procedures. You can complete the procedural instructions by using either the mouse or the keyboard. To choose a command from a menu, you can use the mouse or press shortcut keys.
Bold type	Words or characters you type. For example, if the manual instructs you to type **cd system** you type the lowercase letters "cd" followed by a space and the lowercase letters "system."
Italic type	Specialized terms.
	Titles of other books or manuals.
	Place holders for items you must supply, such as a filename. For example, when the manual says to type **cd** *directory_name*, you type the letters "cd" followed by a space and then the name of a directory.

Keyboard Conventions

All key names are in capital letters. For example, the Control key is CTRL and the Escape key is ESC. (The keys on your keyboard may not be labeled exactly as they are in this manual.)

Keys	Comments
Shortcut keys	Keys frequently used in combinations or sequences as shortcut keys. For example, SHIFT+F1 means to hold down the SHIFT key while pressing F1, and ALT, F, A means to press and release each of these keys in order.
RETURN and ENTER key	These keys perform the same action in EREPS.
Arrow keys (←, ↑, →, ↓) HOME, END, TAB, SHIFT TAB, PAGE UP, PAGE DOWN	Many keys may be used to move you to a data insertion point. Some keys may be used in combinations, such as CTRL+HOME. Some key combinations, such as SHIFT+↑, are not available on all keyboards.
Numeric keypad keys	If you have an extended keyboard, you can type numbers with the numeric keypad if you first press the NUM LOCK key.

Mouse Conventions

The most efficient method of moving about within an EREPS program is by using a mouse. You can use a single or multiple-button mouse with EREPS.

◆ If you have a multiple-button mouse, the left mouse button is the primary mouse button. Any procedure that requires you to click the secondary button will refer to

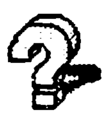
it as the "right mouse button." Using the center button of a three-button mouse may give unpredictable results.

◆ "Point" means to position the mouse pointer until the tip of the pointer rests on whatever you want to point to on the screen.

◆ "Click" means to press and then immediately release the mouse button without moving the mouse.

◆ "Drag" means to point and then hold down the mouse button as you move the mouse.

EREPS Support Services



If you have a question about EREPS, first look in the printed documentation, or consult Help. Each input parameter, menu item, program option, and special function key has its own on-line help. The help defines or describes the parameter and shows any associated units, limits, and default values. Special considerations, cautions, and proper parameter uses are also described.

► **To use the on-line help feature.**

1. "Highlight" the item in question by moving the highlight bar over it with the arrow keys, or point to it and click the left mouse button.

2. Press the F1 key or click the HELP text.

Technical Support

No-charge support for EREPS, including help with software-related problems or questions and training and consultation in the proper use of the EREPS products, is available from NCCOSC, RDT&E Division (NRaD) engineers. Support is available

between 7:15 A.M. and 4:45 P.M. Pacific Time, Monday through Thursday, excluding holidays. NRaD working hours are such that every other Friday is a non-working Friday. Should you call on the non-working Friday, you may leave a message and an engineer will return your call as soon as possible.

For technical support via a toll call, dial (619) 553-1424; or via the Defense Switching Network (DSN), dial 553-1424.

For technical support via the Internet, electronically mail your questions to 543@nosc.mil.

For technical support via facsimile, dial (619) 553-1417.

EREPS Registration

An ASCII text file, register.txt, is on the EREPS distribution diskette. This file contains an EREPS registration form. If you received your copy of EREPS from us or from someone else, please take a minute to complete this form and mail it to us at:

NCCOSC RDTE DIV 543
53170 WOODWARD ROAD
SAN DIEGO CA 92151-7385

Registration of your EREPS diskette will ensure your receipt of any future upgrades of the EREPS software, newsletters, or technical support documentation.

What's New?

EREPS version 3.0 is an upgrade to version 2.2 released in December 1992. The propagation models of COVER, PROPR, and PROPH remain the same except for minor programming corrections. Significant changes have been made to the RAYS program and to the entire EREPS user interface.

◆ Complete context-sensitive help is available at the push of the F1 key. Operation of all EREPS programs, new user interface changes, and instructions on using new utilities are described in detail.

◆ Mouse support is much more dynamic. You may move between program options, select items from pop-up menus, and customize the EREPS graphic displays with a click of the mouse button.

◆ EREPS customizing features are much more robust. You may define colors, line and text styles, and program initialization preferences.

◆ The user-data file system is expanded and structured similar to that of other programs such as Symantec Norton Commander® or Microsoft Windows™.

◆ The SDS program no longer requires separate supporting map and data files. The SDS.EXE program is completely stand-alone.

◆ The RAYS program is completely restructured and vastly expanded to include the following capabilities.

Additional methods of defining a modified refractivity profile are available. These methods are:

- Numerical height versus *M*-units or *N*-units.
- Pressure, temperature, and humidity, where humidity may be relative humidity, dew point temperature, or dew point depression temperature.
- World Meteorological Organization (WMO) Message.

- Evaporation Duct Calculations.
- Draw profile graphically.
- Profile Characteristics.
- Environmental file.

The raytrace propagation model is now range-dependent, allowing 15 modified refractivity profiles at irregular ranges. Range dependency allows for the examination of raytrace propagation through frontal boundaries, in varying surface-based and elevated ducting environments, and in fluctuating evaporation duct environments.

Any modified refractivity profile you create with the RAYS program may be saved to an ASCII file. This file may then serve as an environmental input for the Radio Physical Optics (RPO) electromagnetic propagation model. NRaD technical document 2403, "*Radio Physical Optics CSCI Software Document*," December 1992, competely describes this hybrid ray-optic and parabolic equation propagation model. The COVER, PROPR, and PROPH programs can display the RPO model output.

The RPO program is not part of the EREPS 3.0 distribution package. For U.S. government agencies and their contractors, inquiries about RPO may be made to our technical support address.

Getting Started

Installing EREPS

Hardware and Operating System Requirements

You may install and run EREPS 3.0 on an IBM PC, Personal Computer AT, PC/XT, or 100 percent compatible computer with an EGA or better graphics capability. Because of the redesigned user interface, we recommend, as a minimum, an AT class machine. EREPS 3.0 requires MS-DOS® version 3.0 or greater. Each EREPS program requires a different minimum amount of random access memory (RAM) to operate at its full potential. The RAYS program is the most demanding at 510 kilobytes. A hard disk is required for the initial expansion of the individual programs. Once installed, however, the individual EREPS programs may be copied to and run from floppy diskettes. A mouse is not required but is highly recommended.

You may run EREPS 3.0 with an MS-DOS® emulation under other operating systems such as Microsoft Windows™ or Windows NT™, IBM OS/2™, or Sun Microsystems SunOS™. Its stability, however, is extremely dependent upon your hardware and the operating system's configuration. For example, while EREPS will run under OS/2 in the full screen mode, it will not run under OS/2 configured for the high-performance file system.

EREPS 3.0 does not contain an internal capability to capture and print screen graphics. Therefore, EREPS does not require a printer. If you have a printer and would like paper or overhead slide copies of the EREPS screens, you must provide your own screen capture and print software. An example of such a utility is the GRAPHICS.EXE program provided with MS-DOS® 5.0 and above. The GRAPHICS.EXE terminate-and-stay-resident (TSR) program must be loaded into your machine's memory prior to starting EREPS. If you are running EREPS 3.0 within a Windows™ shell, you may use the PRINT

SCRN key to copy the screen to the clipboard and then paste it to another program for printing.

Some screen capture and print utilities, such as Pizazz Plus by Application Techniques, Inc., will cause the EREPS program to behave erratically.

Software Installation

EREPS 3.0 comes on one high-density 3.5-inch floppy diskette. The individual EREPS programs are compressed into a single, self-expanding file called EREPS30.EXE.

► **To install the EREPS programs.**

Step	Notes
1	Create a destination directory on your hard drive. **mkdir c:*destination_directory***
2	Insert the distribution disk in either drive A or drive B and change to that directory. **a:** or **b:**
3	Copy the distribution disk's contents to your destination directory. **copy *.* c:*destination_directory***
4	Change to the destination directory. **cd c:*destination_directory***

5 Type **EREPS30**.

Once expanded, you may copy the individual EREPS (*.exe) programs to and run them from a floppy diskette. Do **NOT** try to expand the EREPS30.EXE file while your current drive is the floppy drive. You may also want to delete the EREPS30.EXE file from the hard disk to conserve disk space.

EREPS Contents

EREPS 3.0 consists of the following files.

- PROPR.EXE — Generates a display of propagation-loss, propagation-factor, or radar signal-to-noise ratio versus range under a variety of environmental conditions from which signal levels relative to a specified threshold or maximum free-space range can be determined.
- PROPH.EXE — Provides a display similar to PROPR except the independent plot variable is receiver height rather than range.
- COVER.EXE — Provides a height-versus-range display showing the area where signal levels meet or exceed your specified thresholds.
- RAYS.EXE — Displays altitude-versus-range trajectories of a series of rays for your specified refractive-index profile, and includes an option to display altitude error relative to a standard atmosphere.
- SDS.EXE — Displays an annual climatological summary of evaporation duct, surface-based duct, and other meteorological parameters. SDS may be used as a source of environmental data for the PROPR, PROPH, and COVER programs.
- FFACTR.BAS — FFACTR is not an executable program but a program source code. It is compiled external to the EREPS system to produce a

stand-alone program. You can also incorporate it into your programs as a called subroutine. The latter use might require you to translate FFACTR into another program language. FFACTR is structured as a subroutine that returns a propagation factor in decibels for specified environmental and EM system parameters.

- REGISTER.TXT — An ASCII file containing the EREPS registration form.
- EREPS.HLP — An ASCII help file used by all EREPS programs. You may print this file on a printer, but printing it is not particularly recommended. Each item of help in the file is "keyed" to a short prompt as seen on an EREPS page. The @ symbol is used to separate short prompts. For example, @TRAN HT@ identifies help for transmitter height. If you do choose to print this file, we suggest you first copy it, giving it a different name. Then, using an ASCII text editor with the new file, remove the first 112 lines. These lines provide instructions to EREPS, allowing help on a particular topic to be found quickly.
- README.TXT — An ASCII text file containing version 3.0 update information.
- CNVRT2X3.EXE — A utility program to convert your EREPS version 2.x electromagnetic system files to the EREPS 3.0 format.

Starting EREPS

GO

► **To start any EREPS program.**

Step	Notes
1	At the MS-DOS® prompt, change to the directory containing the .EXE file of the program. **cd c:*destination_directory***

2 Type the program's name.

propr or **cover**, etc.

All EREPS programs may be started with two options on the MS-DOS® command line, -nomouse (or /nomouse) and -f filename (or /F filename). The /nomouse option will turn off all mouse support. If you don't have a mouse, the EREPS programs should still function without the /nomouse option. If you experience problems, however, start the program with the -nomouse option. The /f filename option will cause the program to read a file containing your customized startup information. For example, to start the COVER program with no installed mouse, type

cover /nomouse

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The Atmospheric Environment

Structure and Characteristics of the Earth's Atmosphere

The earth's atmosphere is a collection of many gases together with suspended particles of liquid and solids. Excluding variable components such as water vapor, ozone, sulfur dioxide, and dust, the gases of nitrogen and oxygen occupy about 99 percent of the volume, with argon and carbon dioxide being the next two most abundant gases. From the earth's surface to an altitude of approximately 80 kilometers, mechanical mixing of the atmosphere by heat-driven air currents evenly distributes the components of the atmosphere. At about 80 kilometers, the mixing decreases to the point where the gases tend to stratify in accordance with their weights.

The lower, well-mixed portion of the atmosphere is called the homosphere, while the higher, stratified portion is called the heterosphere. The bottom portion of the homosphere is called the troposphere.

The troposphere extends from the earth's surface to an altitude of 8 to 10 kilometers at polar latitudes, 10 to 12 kilometers at middle latitudes, and up to 18 kilometers at the equator. It is characterized by a temperature decrease with height. The point at which the temperature ceases to decrease with height is known as the tropopause. The average vertical temperature gradient of the troposphere varies between 6 and 7 degrees Celsius per kilometer.

The concentrations of gas components of the troposphere vary little with height, except for water vapor. The water vapor content of the troposphere comes from evaporation of water from oceans, lakes, rivers, and other water reservoirs. Differential heating of land and ocean surfaces produces vertical and horizontal wind circulation that distribute the water vapor throughout the troposphere. The water vapor content of the troposphere rapidly decreases with height. At an altitude of 1.5 kilometers, the water vapor content is approximately half of the surface content. At the tropopause, the content is only a few thousandths of what it is at the surface.

In 1925, the International Commission for Aeronavigation defined the *international standard atmosphere*. This is a hypothetical atmosphere having an

arbitrarily selected set of pressure and temperature characteristics that reflect an average condition of the real atmosphere.

Refraction

Index of Refraction

The term *refraction* refers to the property of a medium to bend an electromagnetic wave as it passes through the medium. A measure of the amount of refraction is the index of refraction, n, defined as the velocity, c, of propagation in free space (away from the influence of the earth or other objects) to the velocity, v, in the medium:

$$n = \frac{c}{v}. \qquad (1)$$

Refractivity and Modified Refractivity

The normal value of n for the atmosphere near the earth's surface varies between 1.000250 and 1.000400. For studies of propagation, the index of refraction is not a very convenient number, therefore a scaled index of refraction, N, called *refractivity*, has been defined. At microwave frequencies and below, the relationship between the index of refraction n and refractivity N for air that contains water vapor is given as

$$N = (n-1)10^6 = \frac{77.6p}{T} + \frac{e_s 3.73 \cdot 10^5}{T^2}, \qquad (2)$$

where e_s is the partial pressure of water vapor in millibars or

$$e_s = \frac{rh\ 6.105\ e^x}{100}, \qquad (3)$$

where

$$x = 25.22\frac{T - 273.2}{T} - 5.31\ \mathrm{LOG}_e\left(\frac{T}{273.2}\right) \text{and} \qquad (4)$$

$p =$ atmosphere's barometric pressure in millibars,
$T =$ atmosphere's absolute temperature in Kelvin,
$rh =$ atmosphere's relative humidity in percent.

Thus, the atmospheric refractivity near the earth's surface would normally vary between 250 and 400 N-units.

Since the barometric pressure and water vapor content of the atmosphere decrease rapidly with height while the temperature decreases slowly with height, the index of refraction, and therefore refractivity, normally decreases with increasing altitude.

As a tool in examining refractive gradients and their effect upon propagation, a *modified refractivity*, defined as

$$M = N + 0.157\ h \qquad \text{for altitude } h \text{ in meters and}$$
$$M = N + 0.048\ h \qquad \text{for altitude } h \text{ in feet,} \tag{5}$$

is often used in place of the refractivity.

Effective Earth Radius Factor

In free space, an electromagnetic wave will travel in a straight line because the index of refraction is the same everywhere. Within the earth's atmosphere, however, the velocity of the wave is less than that of free space, and the index of refraction normally decreases with increasing altitude. Therefore, the propagating wave will be bent downward from a straight line. It is frequently more convenient, however, to compute refractive effects in terms of waves traveling in straight lines. This may be approximated by replacing the actual earth's radius with an effective earth radius and replacing the actual atmosphere by one that is homogeneous in nature.

The *effective earth radius factor*, k, is defined as the factor that is multiplied by the actual earth radius, a, to give the effective earth radius a_e. Therefore $a_e = k\,\mathrm{a}$. k is the parameter used by PROPR, PROPH, and COVER to account for average refractive effects in the optical region and is related to the average N- or M-unit gradient by

$$k = \frac{1}{\left(1 - 10^{-6}\ \mathrm{a}\dfrac{\mathrm{d}N}{\mathrm{d}z}\right)} = \frac{1}{\left(10^{-6}\ \mathrm{a}\dfrac{\mathrm{d}M}{\mathrm{d}z}\right)}, \tag{6}$$

where dN/dz and dM/dz are the N and M gradients, respectively, and z is in the same units as a. The mean earth radius is generally taken to be $6.371 \cdot 10^6$ meters. For standard refractivity conditions where $dN/dz = -0.039$ N-units per meter or $dM/dz = 0.118$ M-units per meter, $k = 1.33$ or four-thirds.

Refractive Gradients

Standard and Normal

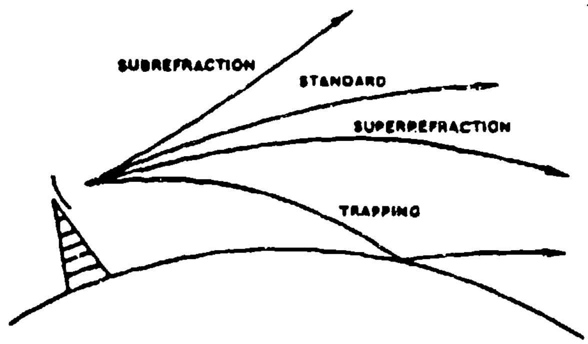

Figure 2-1: Refractive Conditions

The refractivity distribution within the atmosphere is nearly an exponential function of height (Bean and Dutton, 1968). The exponential decrease of N with height close to the earth's surface (within 1 kilometer) is sufficiently regular, however, to allow an approximation of the exponential function by a linear function, a linear function that is assumed by the effective earth's radius model. This linear function is known as a *standard* gradient and is characterized by a decrease of 39 N-units per kilometer or an increase of 118 M-units per kilometer. A standard gradient will cause traveling EM waves to bend downward from a straight line. Gradients that cause effects similar to a standard gradient but vary between 0 and -79 N-units per km or between 79 and 157 M-units per km are known as *normal* gradients.

Subrefraction

If the motions of the atmosphere produce a situation where the temperature and humidity distribution creates an increasing value of N with height, the wave path would actually bend upward and the energy would travel away from the earth. This is termed *subrefraction*. Although this situation rarely occurs in nature, it still must be considered when assessing electromagnetic systems' performance.

Superrefraction

If the troposphere's temperature increases with height (temperature inversion) and/or the water vapor content decreases rapidly with height, the refractivity gradient will decrease from the standard. The propagating wave will be bent downward from a straight line more than normal. As the refractivity gradient continues to decrease, the radius of curvature for the wave path will approach the radius of curvature for the earth. The refractivity gradient for which the two radii of curvature are equal is referred to as the *critical* gradient. At the critical gradient, the wave will propagate at a fixed height above the ground and will travel parallel to the earth's surface. Refraction between the normal and critical gradients is known as *superrefraction*.

Trapping

Should the refractivity gradient decrease beyond the critical gradient, the radius of curvature for the wave will become smaller than that of the earth's. The wave will either strike the earth and undergo surface reflection, or enter a region of standard refraction and be refracted back upward, only to reenter the area of refractivity gradient that causes downward refraction. This refractive condition is called *trapping* because the wave is confined to a narrow region of the troposphere. The common term for this confinement region is a tropospheric duct or a tropospheric *waveguide*. It should be noted that a tropospheric waveguide is not a waveguide in the true sense of the word because there are no rigid walls that prevent the escape of energy from the guide.

The refractivity gradients and their associated refractive conditions are summarized in the following table.

Table 2-1: Refractive Gradients and Conditions

	N-Gradient	*M*-Gradient
Trapping	< -157 *N*/km < 48 *N*/kft	< 0 *M*/km < 0 *M*/kft
Superrefractive	-157 to - 79 *N*/km - 48 to - 24 *N*/kft	0 to 79 *M*/km 0 to 24 *M*/kft
Normal	- 79 to 0 *N*/km - 24 to 0 *N*/kft	79 to 157 *M*/km 24 to 48 *M*/kft
Subrefractive	> 0 *N*/km > 0 *N*/kft	> 157 *M*/km > 48 *M*/kft

Atmospheric Ducts

A duct is a channel in which electromagnetic energy can propagate over great ranges. To propagate energy within a duct, the angle the electromagnetic system's energy makes with the duct must be small, usually less than 1 degree. Thicker ducts in general can support trapping for lower frequencies. The vertical distribution of refractivity for a given situation must be considered as well as the geometrical relationship of transmitter and receiver to the duct in order to assess the duct's effect at any particular frequency.

Ducts not only give extended radar detection or Electronic Support Measures (ESM) intercept ranges for systems within the duct, they may also have a dramatic effect upon transmitter/receiver systems that transcend duct boundaries. For example, an air target that would normally be detected may be missed if the radar is within or just above the duct and the target is just above the duct. This area of reduced coverage is known as a radar *hole* or shadow zone.

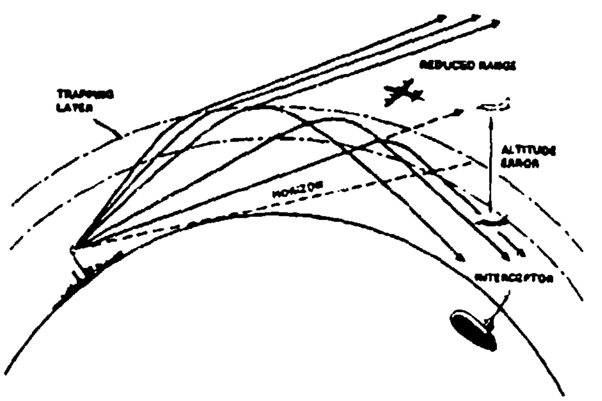

Figure 2-2: Ducting Consequences

Although the duct acts like a waveguide for the energy, this waveguide does not have rigid and impenetrable boundaries, except for the earth's surface in cases where the duct's bottom lies at the surface. Therefore, energy is continually *leaking* from the duct. While the energy level within a radar hole may be insufficient for radar detection, it may be sufficient for ESM intercept of the radar.

Surface Ducts

Several meteorological conditions will lead to the creation of ducts. If these conditions cause a trapping layer to occur, such that the base of the resultant duct is at the earth's surface, a surface duct is formed. There are three types of surface ducts based on the trapping layer's relationship to the earth's surface. These are a surface duct created from a surface-based trapping layer, referred to as a *surface duct*; a surface duct created

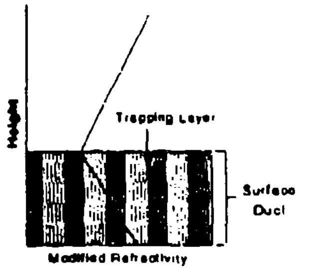

Figure 2-3: Surface duct.

from an elevated trapping layer, commonly referred to by IREPS and EREPS as a *surface-based duct*; and a surface duct created by a rapid decrease of relative humidity immediately adjacent to the air-sea interface. Because this latter duct is a nearly permanent worldwide feature, it is referred to as an *evaporation duct*. EREPS allows for separate inputs for the surface-based duct and the evaporation duct. EREPS models (except for the RAYS program) do not allow for a surface duct created from a surface-based trapping layer.

Surface-based ducts occur when the air aloft is exceptionally warm and dry compared with the air at the earth's surface. Several meteorological conditions which may lead to the formation of surface-based ducts.

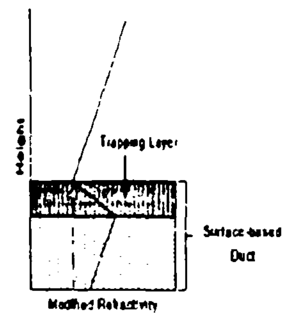

Figure 2-4: Surface-based Duct.

Over the ocean and near land masses, warm, dry continental air may be advected over the cooler water surface. Examples of this type of advection are the Santa Ana of southern California, the sirocco of the southern Mediterranean, and the shamal of the Persian gulf. This advection will lead to a temperature inversion at the surface. In addition, moisture is added to the air by evaporation, producing a moisture gradient to strengthen the trapping gradient. This type of meteorological condition routinely leads to a surface duct created by a surface-based trapping condition, a surface duct type not modeled within EREPS. However, as one moves from the coastal environment into the open ocean, this trapping layer may well rise from the surface, thereby creating the surface-based duct known by EREPS. Surface-based ducts tend to be on the leeward side of land masses and may occur both during the day or at night. In addition, surface-based ducts may extend over the ocean for several hundred kilometers and may be very persistent (lasting for days).

Another method of producing surface-based ducting conditions is by divergence (spreading out) of relatively cool air under a thunderstorm. While this method may not be as frequent as the other methods, it may still enhance surface propagation during the thunderstorm activity, usually on the order of a few hours.

With the exception of thunderstorm conditions, surface-based ducting is associated with fair weather, with increased occurrence of surface-based ducts during the warmer months and in more equatorial latitudes. Any time the troposphere is well-mixed, such as with frontal activity or with high wind conditions, surface-based ducting is decreased.

An interesting feature of surface-based ducts is the skip zone near the normal horizon, in which the duct has no influence. This skip zone is easily illustrated using a raytrace program such as RAYS, and a model to account for its effects is included in all the EREPS programs. It should be noted that the surface duct created from a surface-based trapping layer does not have this skip zone phenomenon and, again, is not modeled within EREPS.

Evaporation Ducts

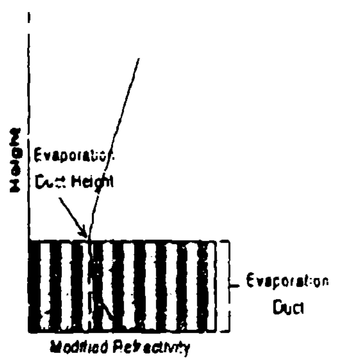

Figure 2-5: Evaporation Duct

As can be seen from equation 2, a change in the moisture distribution without an accompanying temperature change can also lead to a trapping refractivity gradient. The air in contact with the ocean's surface is saturated with water vapor. A few meters above the surface the air is not usually saturated, so there is a decrease of water vapor pressure from the surface to some value well above the surface. The rapid decrease of water vapor initially causes the modified refractivity, M, to decrease with height, but at greater heights the water vapor distribution will cause M to reach a minimum and, thereafter, increase with height. The height at which M reaches a minimum is called the *evaporation duct height*.

Evaporation ducts exist over the ocean, to some degree, almost all of the time. The duct height varies from a meter or two in northern latitudes during winter nights to as much as 40 meters in equatorial latitudes during summer days. On a world average, the evaporation duct height is approximately 13 meters. It should be emphasized that the evaporation duct "height" is not a height below which an antenna must be located in order to have extended propagation but a value that relates to the duct's strength or its ability to trap radiation. The duct strength is also a function of wind velocity. For unstable

atmospheric conditions, stronger winds generally result in stronger signal strengths (or less propagation loss) than do weaker winds.

Since the evaporation duct is much weaker than the surface-based duct, its ability to trap energy is highly dependent on frequency. Generally, the evaporation duct is only strong enough to affect electromagnetic systems above 3000 MegaHertz.

The proper assessment of the evaporation duct is best performed by making surface meteorological measurements and inferring the duct height from the meteorological processes occurring at the air/sea interface, as demonstrated by Jeske (1965) and Paulus (1985). The evaporation duct height cannot be measured using a radiosonde or a microwave refractometer. With the advent of newer, high-resolution sondes that may be lowered to the surface from a ship, the impression is given that the evaporation duct may be measured directly. For practical applications, however, this impression is false and a direct measurement should not be attempted. Due to the turbulent nature of the troposphere at the ocean surface, a refractivity profile measured at one time would most likely not be the same as one measured at another time, even when the two measurements are seconds apart. Therefore, any measured profile would not be representative of the average evaporation ducting conditions, the conditions that an assessment system must consider.

The long-term statistical frequency distribution of evaporation ducts is readily available through the SDS program for most areas of the world.

Elevated Ducts

If meteorological conditions cause a trapping layer to occur aloft, such that the base of the duct occurs above the earth's surface, the duct is referred to as an *elevated* duct.

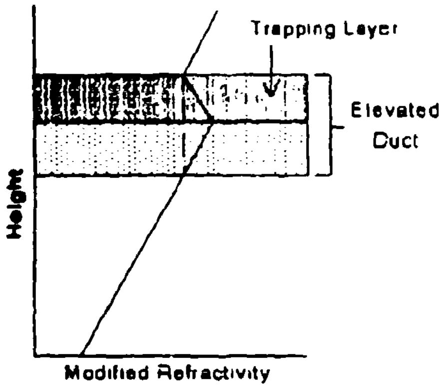

Figure 2-6: Elevated Duct.

Great semipermanent surface high-pressure systems, centered at approximately 30 degrees north and south latitude, cover the ocean areas of the world. Poleward of these systems lay the mid-latitude westerly winds and, equatorward, the tropical easterlies or the tradewinds. Within these high- pressure systems, large-scale subsidence of air causes heating as the air undergoes compression. This leads to a layer of warm, dry air overlaying a cool, moist layer of air (often called the marine boundary layer). The resultant inversion is referred to as the tradewind inversion and may create a strong ducting condition at the top of the marine boundary layer. Elevated ducts may vary from a few hundred meters above the surface at the eastern part of the tropical oceans to several thousand meters at the western part. For example, along the southern California coast, elevated ducts occur an average of 40 percent of the time, with an average top elevation of 600 meters. Along the coast of Japan, elevated ducts occur an average of 10 percent of the time, with an average top elevation of 1500 meters.

It should be noted that the meteorological conditions necessary for a surface-based duct are the same as those for an elevated duct. In fact, a surface-based duct may slope upward to become an elevated duct as warm, dry continental air glides over cool, moist marine air. The tradewind inversion may also intensify, thereby turning an elevated duct into a surface-based duct.

Standard Wave Propagation Mechanisms

Propagation Loss, Propagation Factor, Signal-to-Noise

PROPR and PROPH present their results in terms of propagation loss, propagation factor, or radar signal-to-noise ratio, all expressed in decibels (dB). The definitions of each term, as used within EREPS, is

Propagation loss: The ratio, expressed in decibels, of the effective radiated power transmitted in the direction of maximum radiation of the antenna pattern to the power received at any point by an omnidirectional antenna.

Propagation factor: The ratio, expressed in decibels, of the actual field strength at a point to the field strength that would occur at the same range in free-space in the direction of maximum radiation.

Signal-to-noise ratio: The ratio, expressed in decibels, of the signal received at the input of the radar receiver to the noise generated within the receiver itself.

For the purposes of EREPS, the signal level is based upon the reflection from a target of specified radar cross-section, all the engineering parameters of the radar (such as radiated power, antenna gain, losses, etc.), and the applicable propagation factors.

Widely used definitions of path loss are based on omnidirectional antennas. In PROPR and PROPH, propagation loss is equivalent to path loss when an omnidirectional antenna is specified. Propagation loss is closely related to many definitions of transmission loss. Transmission loss generally includes effects from both an antenna pattern and the absolute gain of the antenna, whereas propagation loss only includes the pattern effects, with the gain normalized to 1 (i.e., 0 dB) in the direction of maximum transmission. Therefore, propagation loss would be equal to transmission loss plus the antenna gain in decibels.

To clearly indicate that antenna pattern effects are included, the EREPS definition of propagation factor is frequently referred to by others as pattern-propagation factor. We chose to retain the term "propagation factor" because it is consistent with the term "propagation loss". However, you should be aware that the EREPS propagation factor does include the effects of the antenna pattern.

Free-Space Propagation

The simplest case of electromagnetic wave propagation is the transmission of a wave between a transmitter and a receiver in free space. Free space is defined as a region whose properties are isotropic, homogeneous, and loss-free, i.e., away from the influences

of the earth's atmosphere. In free space, the electromagnetic wave front spreads uniformly in all directions from the transmitter. If a particular point on a wave front is followed over time, the collection of point positions would define a ray. The ray would coincide with a straight line from the transmitter to the receiver.

Standard Propagation

Standard propagation mechanisms are those propagation mechanisms and processes that occur in the presence of a standard atmosphere. These propagation mechanisms are free-space propagation, optical interference (or surface reflection), diffraction, and tropospheric scatter.

Optical Interference and Surface Reflection

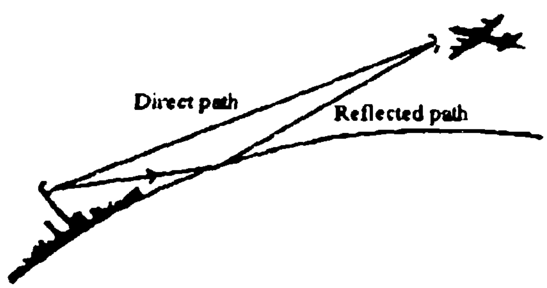

Figure 2-7: Surface Reflection.

When an electromagnetic wave strikes a nearly smooth large surface, such as the ocean, a portion of the energy is reflected from the surface and continues propagating along a path that makes an angle with the surface equal to that of the incident ray.

The strength of the reflected wave is determined by the reflection coefficient, a value which depends upon the frequency and polarization of radiation, the angle of incidence, and the roughness of the reflecting surface.

For shallow incidence angles and smooth seas, typical values of the reflection coefficient are near unity (i.e., the reflected wave is almost as strong as the incidence wave). As the wind speed increases, the ocean surface grows rougher and the reflection coefficient decreases. For a transmitter near the surface, the reflection process results in two paths to a receiver within the line of sight.

As stated above, upon reflection, a portion of the energy is propagated in the direction of initial wave motion. A portion of energy is also reflected backward toward the transmitter. This backward reflected energy is also received by [illegible] and may interfere with the radar's ability to distinguish a desired target. Th[illegible] reflected energy is called *clutter*.

Not only is the magnitude of the reflected wave reduced, but the phase of the wave is also altered. For horizontally or vertically polarized waves at low grazing angles, the phase change upon reflection is approximately 180 degrees. Whenever two or more wave trains traveling over different paths intersect at a point in space, they are said to interfere. If two waves arrive at the same point in phase, they constructively interfere and the electric field strength is greater than either of the two component waves taken alone. If the two waves arrive together out of phase, they destructively interfere and the resultant field strength is weakened.

As the geometry of the transmitter and receiver change, the relative lengths of the direct path and reflected path also change, which results in the direct and reflected wave arriving at the receiver in varying amounts of phase difference. The received signal strength, which is the vector sum of the signal strengths of the direct and reflected wave, may vary up to 6 dB above and 20 dB or more below the free-space value.

Diffraction

Energy tends to follow along the curved surface of an object. Diffraction is the process by which the direction of propagating radiation is changed so that it spreads into the geometric shadow region of an opaque or refractive object that lies in the radiation field. In the earth-atmosphere system, diffraction occurs where the straight-line distance between the transmitter and receiver is just tangent to the earth's surface. For a homogeneous atmosphere, this point of tangency with the earth is referred to as the geometrical horizon. For a nonhomogeneous atmosphere (using an effective earth radius) and at radar and optical frequencies, this point of tangency is referred to as the radar and optical horizon, respectively.

The ability of the electromagnetic wave to propagate beyond the horizon by diffraction is highly dependent upon frequency. The lower the frequency, the more the wave is diffracted. At radar frequencies, the wavelength is small when compared to the

earth's dimensions and little energy is diffracted. At optical frequencies or very short radar wavelengths, the optical horizon represents the approximate boundary between regions of propagation and no propagation.

Tropospheric Scatter

At ranges far beyond the horizon, the propagation loss is dominated by troposcatter. Propagation in the troposcatter region is the result of scattering by small inhomogeneities within the atmosphere's refractive structure, as discussed in chapter 6.

Anomalous Propagation Mechanisms

A deviation from the normal atmospheric refractivity leads to conditions of subrefraction, superrefraction, and trapping as explained earlier. The term *anomalous propagation*, or nonstandard propagation, applies to any of the above listed conditions, but it is most often used when describing those conditions that lead to radar ranges beyond the normal. Many anomalous propagation effects may be seen quite well with a raytrace program such as RAYS.

Subrefractive Layers

A subrefractive layer of the troposphere would cause the propagating energy to bend upward or away from the earth's surface, thereby leading to decreased detection ranges and shortened radio horizons. Altitude errors for height-finding radars will also become evident in a subrefractive environment.

Subrefractive layers may be found at the earth's surface or aloft. In areas where the surface temperature is greater than 30 degrees Celsius, and relative humidities are less than 40 percent (i.e., large desert and steppe regions), solar heating will produce a very nearly homogeneous surface layer, often several hundreds of meters thick. Since this layer is unstable, the resultant convective processes tend to concentrate any available moisture near the top of the layer. This in turn creates a positive N gradient or subrefractive stratum aloft. This layer may retain its subrefractive nature into the early evening hours,

especially if a radiation inversion develops, trapping the water vapor between two stable layers.

For areas with surface temperatures between 10 and 30 degrees Celsius and relative humidities above 60 percent, i.e., the western Mediterranean, Red Sea, Indonesian Southwest Pacific, etc., surface-based subrefractive layers may develop during the night and early morning hours. It is characteristically caused by advection of warm, moist air over a relatively cooler and drier surface. While the *N* gradient is generally more intense than that described above, the layer is often not as thick. Similar conditions may also be found in regions of warm frontal activity.

Superrefractive Layers

Superrefractive conditions are largely associated with temperature and humidity variations near the earth's surface. Inversions aloft, due to large-scale subsidence will lead to superrefractive layers aloft. Superrefractive layers will lead to increased radar detection ranges and extensions of the radio horizon.

The effects of a superrefractive layer upon a surface-based system is directly related to its height above the earth's surface. For airborne systems, the effects of a superrefractive layer depend upon the position of the transmitter and receiver relative to the layer. Both of these factors are related to the electromagnetic wave's angle of layer penetration. The steeper the penetration angle, the less of an effect the layer will have upon propagation. Trapping is an extension of superrefraction because the meteorological conditions for both are the same.

Atmospheric Ducts

In a discussion of ducting conditions upon EM wave propagation, the usual concern is propagation beyond the normal horizon. Within the horizon, however, ducting also has an effect. Ducting can alter the normal lobing pattern caused by the interference of the direct ray and the surface-reflected ray. The relative phase between the direct and reflected path may be changed as well as the relative amplitudes of the two rays. The effect of the duct on the line-of-sight propagation is to reduce the angle of the lowest lobe, bringing it closer to the surface.

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The EREPS Programs

COVER

The COVER program calculates and displays contours of constant electric field strength or propagation loss in the vertical plane for surface-based systems. The propagation mechanisms considered within COVER are optical interference, diffraction, evaporation ducting, surface-based ducting, and water vapor absorption.

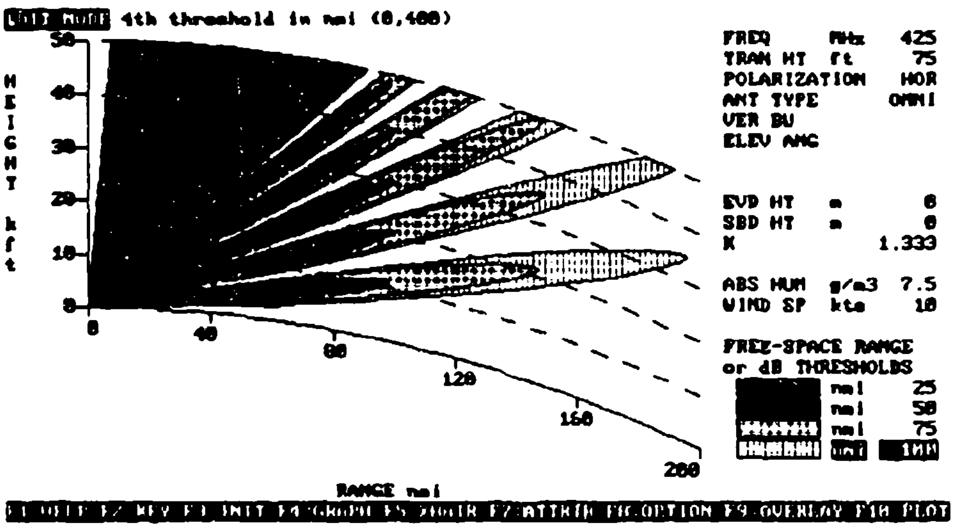
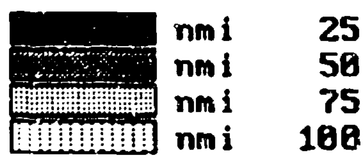


Figure 3-1: COVER Diagram.

The constant electric field strength or propagation loss is also called a system performance threshold. It is defined by a free-space range in units of range or as a propagation loss threshold in decibels. In ocean acoustics, the equivalent threshold is called a figure of merit. Radar detection, ESM intercept, or communication should occur if the target or receiver is within the contour. In any system performance assessment, this threshold value is of primary importance.

► **To define contours of constant electric field strength.**



• Specify the free-space range or decibel threshold directly. You may simultaneously define up to four

thresholds, each representing a different transmitter power, target radar cross-section, receiver sensitivity, etc.

• Specify the various electromagnetic system parameters of a radar (such as frequency, peak power, antenna gain, pulse width, etc.) and the characteristics of the target (such as radar cross-section and Swirling case) and let the COVER program calculate the threshold for you.

FREQ	MHz	425
POLARIZATION		HOR
ANT TYPE		SINX/X
VER BW	deg	10
ELEV ANG	deg	0
ANT GN	dBi	21
HOR BW	deg	11
SCAN RT	rpm	6
PK POW	kW	200
P WIDTH	us	60
PRF	Hz	300
SYS LOSS	dB	6
REC NF	dB	5
RCS	sqm	1
PD		0.5
PFA		1.0E- 8
SW CASE		1-FLCT

Note that an ESM threshold calculation option is not available within the COVER program. Should you desire this type of assessment, you may use the ESM threshold calculation option of the PROPR or PROPH programs and then directly specify it in COVER.

COVER displays threshold contours upon one of three different earth presentations. By selecting from the *RANGE AXIS* value, you may obtain either a *flat*, *curved*, or *dual curved* earth display.

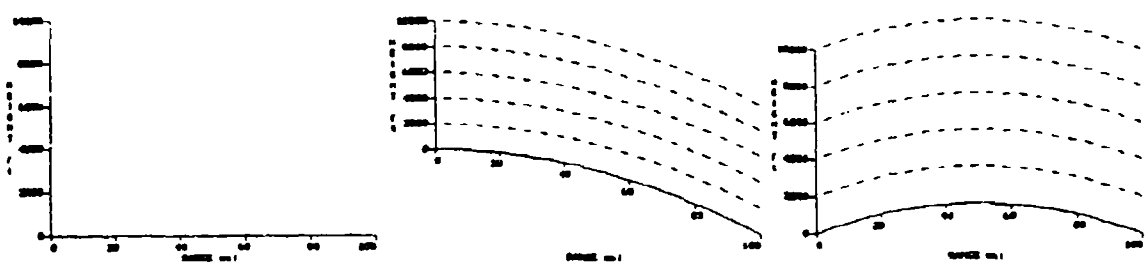


Figure 3-2: Earth's Surface Depictions.

Use caution when selecting the graphic height and range combinations with the curved earth display, as improperly selected values may make the coverage display hard to interpret or misleading upon casual inspection.

Using the COVER diagram

You may use the coverage diagram to investigate the effects of the environment upon a system's performance or to examine the relative performance between several systems, several target parameters, or between individual parameters within the same system. The following series of figures illustrate how you may use a COVER diagram. Various display options are shown in addition to the customized labeling features of EREPS.

- By overlaying a radar system's performance under standard atmospheric conditions with the same system under surface-based ducting conditions, the extended detection range within the surface-based duct is apparent as is the *skip zone* effect of the duct.

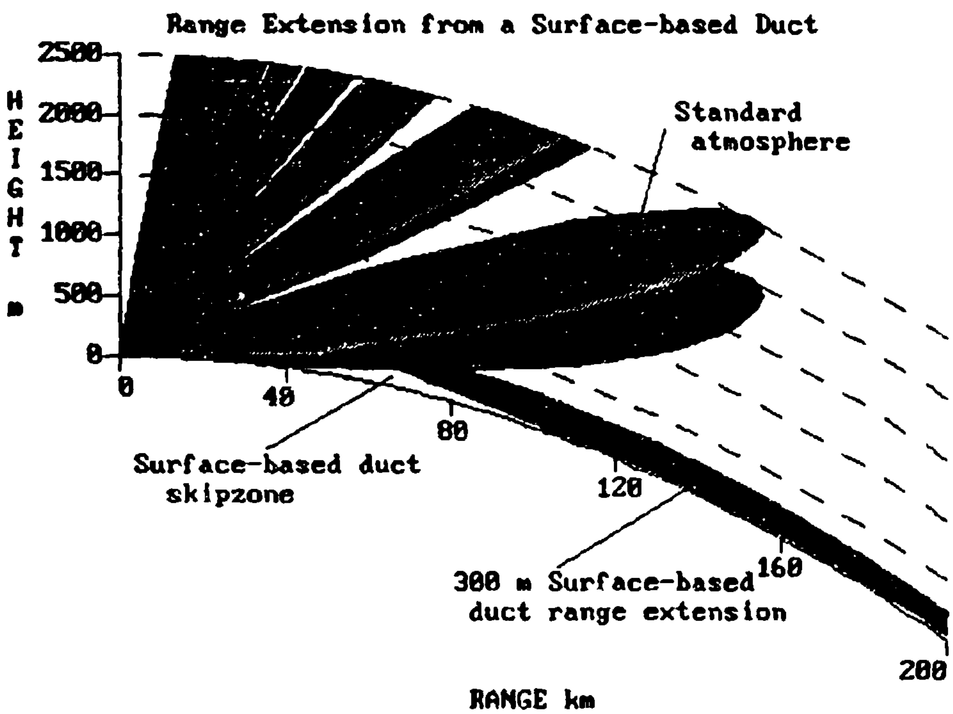


Figure 3-3: Comparing Ducting and Standard Atmosphere Effects.

• You may overlay the effects of the atmosphere upon a system where the frequency is allowed to vary. Under surface-based ducting conditions, the extended detection range within the duct is seen in addition to the "pulling" downward of the interference lobes with higher frequencies.

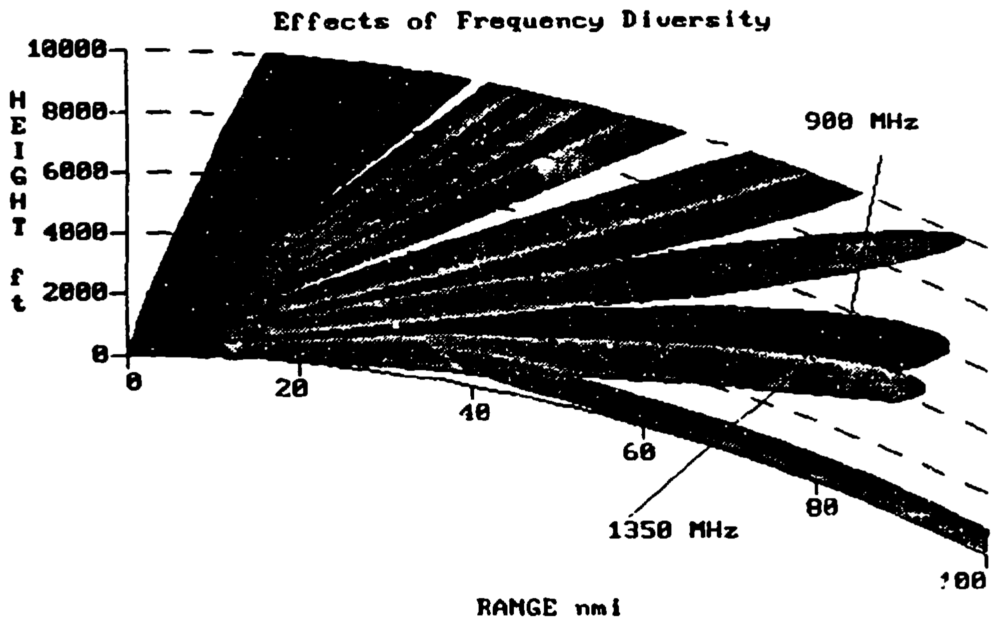


Figure 3-4: Examining Frequency Diversity.

• The radar cross-section of a target such as an aircraft is, among other things, a function of its viewing angle. In general, as the view angle changes from the aircraft's beam to its quarter and on to its nose, the radar-cross section is reduced. This effect may be visualized with a cover diagram where three cross-sections are superimposed.

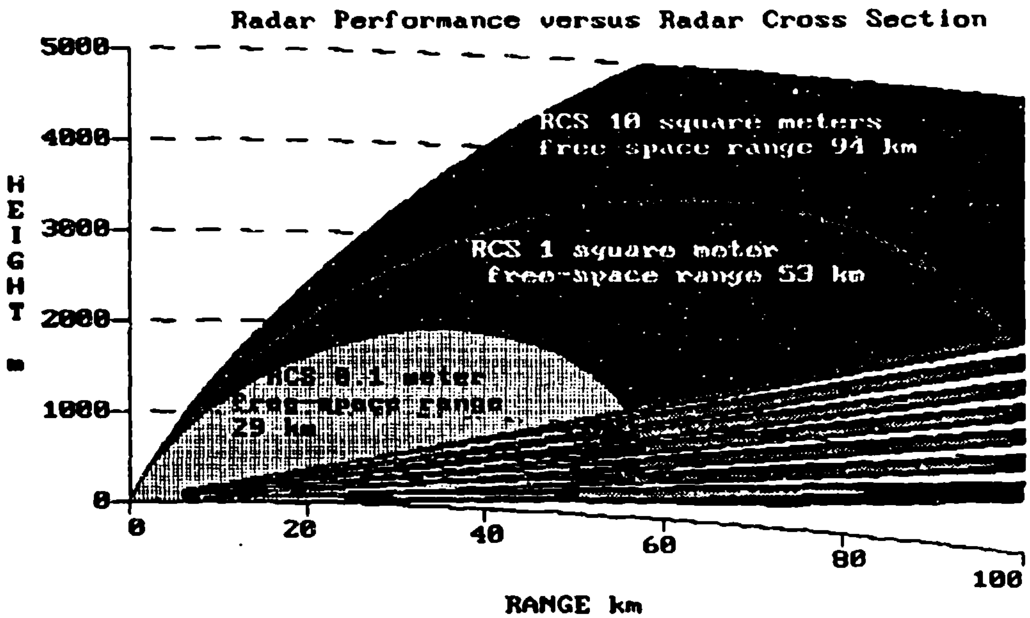


Figure 3-5: Comparing Radar Cross-section Effects.

- There are a number of EM propagation models currently in use within government and industry. If configured correctly, they could write calculated propagation loss values in a binary file with a format readable by EREPS. EREPS (COVER, PROPR, and PROPH) will read the binary file and display the propagation loss data. One such correctly configured program is NRaD's Radio Physical Optics (RPO) model. To use this feature, set the *PROPAGATION MODEL* value found on the INIT mode page to **binary file**.

Propagation loss data are displayed with two resolutions as dictated by the *RESOLUTION* value found on the GRAPH mode page. If the value is set to **pixel**, the data are interpolated to produce a value corresponding to each screen pixel. If the resolution value is set to **file**, uninterpolated data will be plotted at its proper pixel location using the resolution of the values stored in the file. While this method of display is faster than that of pixel, a file that contains data in a coarser mesh than the number of pixels on your screen will result in a "spotty" display, as every screen pixel will not be activated.

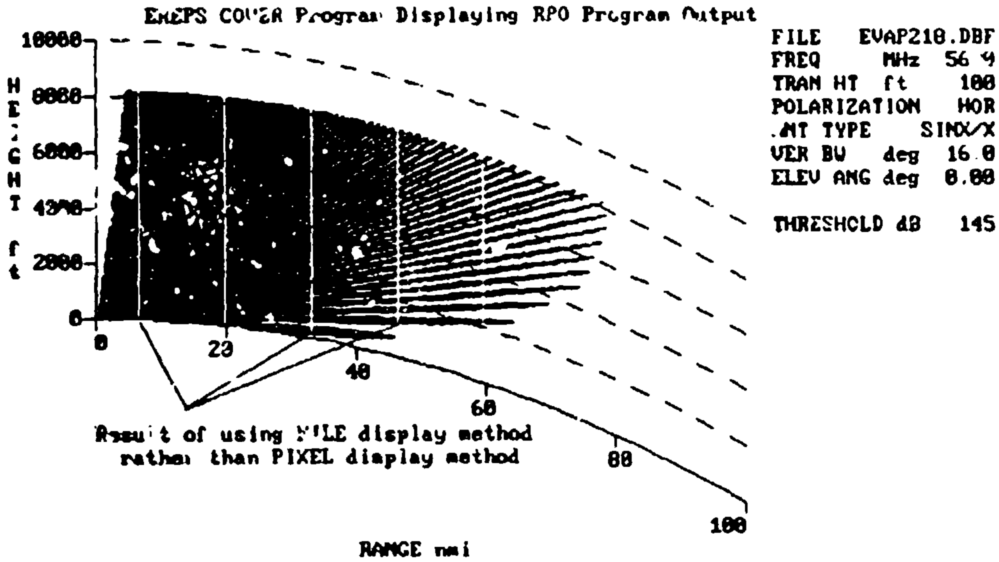


Figure 3-6: COVER Program's File Resolution Display.

The EREPS COVER program is designed to provide support to engineers in assessing propagation effects. Its primary intention is to give "relative" system performance under varying atmospheric conditions. However, it can be used in some tactical applications. You must exercise great care to ensure an appropriate threshold value. These applications are

- Long-range air-search radars, either 2D or 3D, employed against air targets
- Determining "best attack" or "best jam" altitudes
- Own system's vulnerability to airborne ESM systems
- Identification, friend or foe (IFF) range determination
- Hardware performance assessment
- Surface-search radars when employed against low-flying air targets
- Surface-to-air communications

Without a proper understanding of target and radar considerations and the COVER program's assumptions concerning these considerations, the coverage display should NOT be used for

- Surface-search radars employed against surface targets
- Gun or missile fire-control radars.

COVER limitations

COVER uses a parallel ray approximation to the propagation model. The approximation assumes that the direct and sea-reflected rays are nearly parallel. This assumption is quite good at long ranges and higher heights. However, as ranges and heights decrease, the assumption becomes poorer and the COVER program will be in error, with the error becoming worse as ranges and heights decrease. If the COVER program results are suspect, you may compare them to those obtained from PROPR or PROPH. The PROPR and PROPH programs do not make the parallel ray assumption and the calculations will be correct for all geometries.

PROPR and PROPH

PROPR and PROPH calculate and display propagation loss, propagation factor, or radar signal-to-noise ratio in a decibel versus range or height graphic, respectively. The propagation mechanisms considered within the programs are optical interference, diffraction, tropospheric scatter, evaporation ducting, surface-based ducting, and water vapor absorption.

Unlike COVER, which uses contours of electric field strength, PROPR and PROPH thresholds are represented by a horizontal and vertical line, respectively. For the system to function, the propagation loss must not exceed the threshold, whereas the signal-to-noise ratio must exceed the threshold.

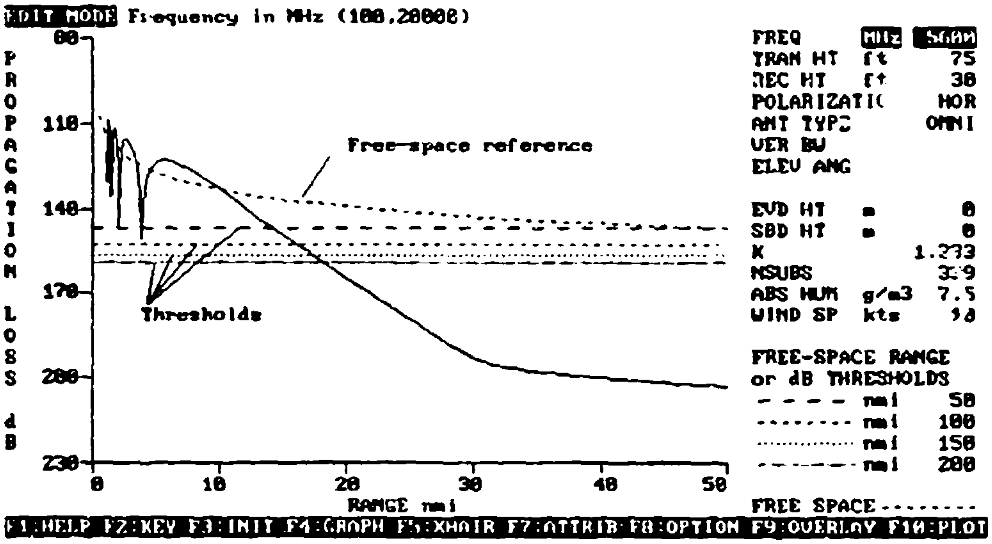


Figure 3-7: PROPR Diagram.

PROPR and PROPH allow you to define the threshold in one of three ways.

► **To define thresholds of electric field strength.**

• Specify the free-space range or threshold directly. You may simultaneously define up to four thresholds, each representing a different receiver sensitivity, transmitter power, probability of detection, target radar cross-section, etc.

```
- - - -  nmi   50
-------- nmi  100
........ nmi  150
———————  nmi  200
```

• Specify the various electromagnetic system parameters of a transmitter and ESM receiver and let PROPR or PROPH calculate the threshold for you. Note the COVER program does not calculate ESM intercept thresholds. You may use this option to calculate the threshold and then directly specify it in the COVER program.

```
ANT GN    dBi   32
PK POW    kW   285
SYS LOSS  dB   8.4
ESM SENS  dBm  -80
```

```
FREQ         MHz  5600
POLARIZATION      HOR
ANT TYPE         SINX/X
VER BW       deg    10
ELEV ANG     deg     0
ANT GN       dBi    32
HOR BW       deg   1.5
SCAN RT      rpm    15
PK POW       kW    285
P WIDTH      us    1.3
PRF          Hz    650
SYS LOSS     dB    8.4
REC NF       dB     14

RCS          sqm     1
PD                 0.5
PFA             1.0E- 8
SW CASE         1-FLCT
```

• Specify the various electromagnetic system parameters of a radar (such as frequency, peak power, etc.), and the characteristics of the target and let PROPR or PROPH calculate the threshold for you.

Using the propagation loss diagram

You may use the propagation loss versus range or height display in every situation where a coverage display is appropriate. In fact, the propagation loss versus range or height display may be thought of as a horizontal or vertical slice of a coverage diagram. In the figure below, the COVER diagram is for a 450 MHz, omnidirectional transmitter located at 75 feet above the surface. The PROPR diagram is for the same transmitter with a receiver located at 20,000 feet above the surface. The PROPH diagram is also for the same transmitter and corresponds to a range of 155 nautical miles from the transmitter. At the points labeled "A," the PROPR and PROPH propagation loss curve intersects the system's performance threshold. On the COVER diagram, the point "A" indicates the threshold boundary corresponding to the range of PROPR and height of PROPH. The lines labeled "B" and "C" correspond to interference nulls in the propagation loss of PROPH and PROPR, respectively. Points "B" and "C" on the COVER diagram also coincide with an interference null.

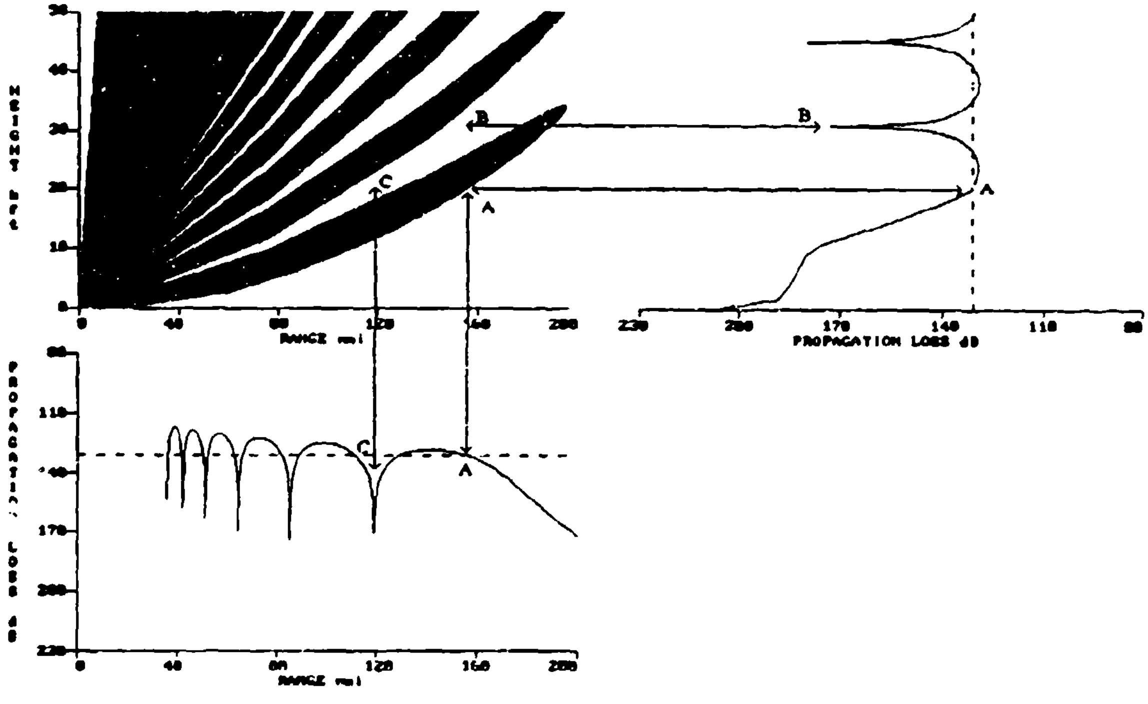


Figure 3-8: Comparison of COVER, PROPR, and PROPH Diagrams.

The following series of figures illustrate how you may use a PROPR or PROPH diagram. Various display options are shown in addition to the customized labeling features of EREPS.

- A comparison of propagation loss under standard atmosphere, 13-meter evaporation duct, and 100-meter surface-based duct conditions. The three propagation regions, optical, diffraction, and troposcatter, are labeled on the standard atmosphere's loss curve.

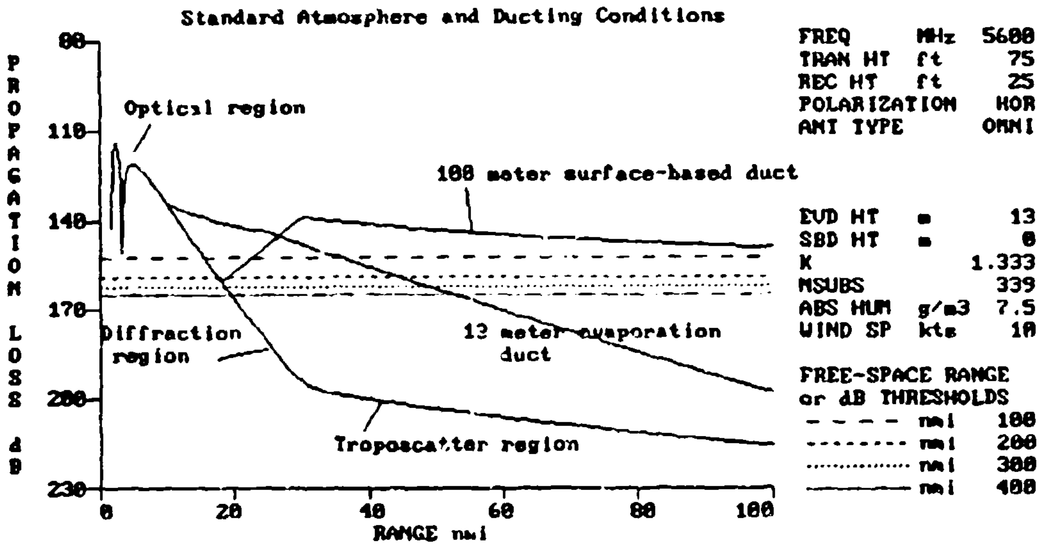


Figure 3-9: PROPR - Comparing Ducting and Standard Atmosphere Effects.

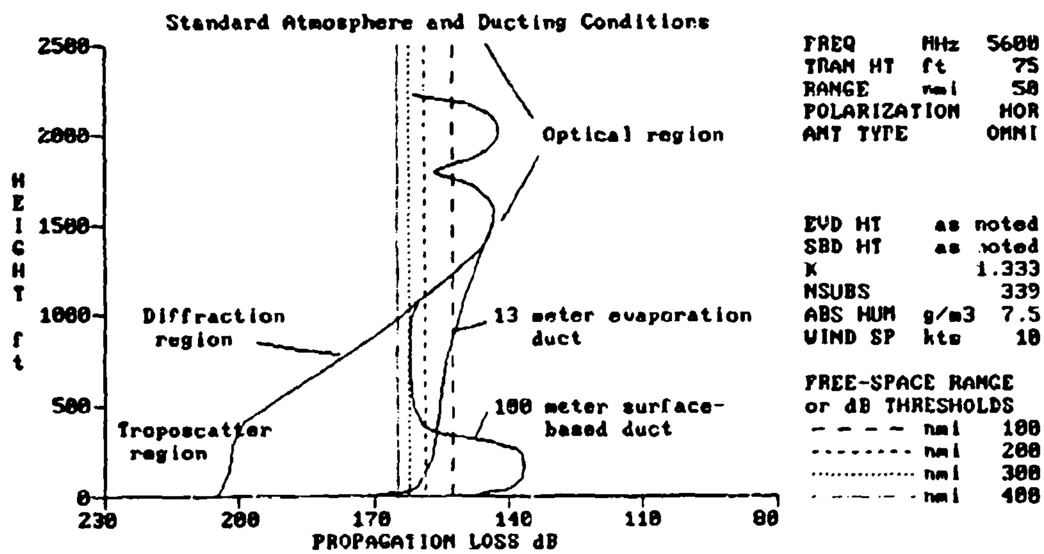


Figure 3-10: PROPH - Comparing Ducting and Standard Atmosphere Effects.

- S-band radar propagation factor under standard atmosphere conditions and 20 knots of wind. Note how the propagation factor decreased with decreasing range and increasing height as the vertical beamwidth limit is reached.

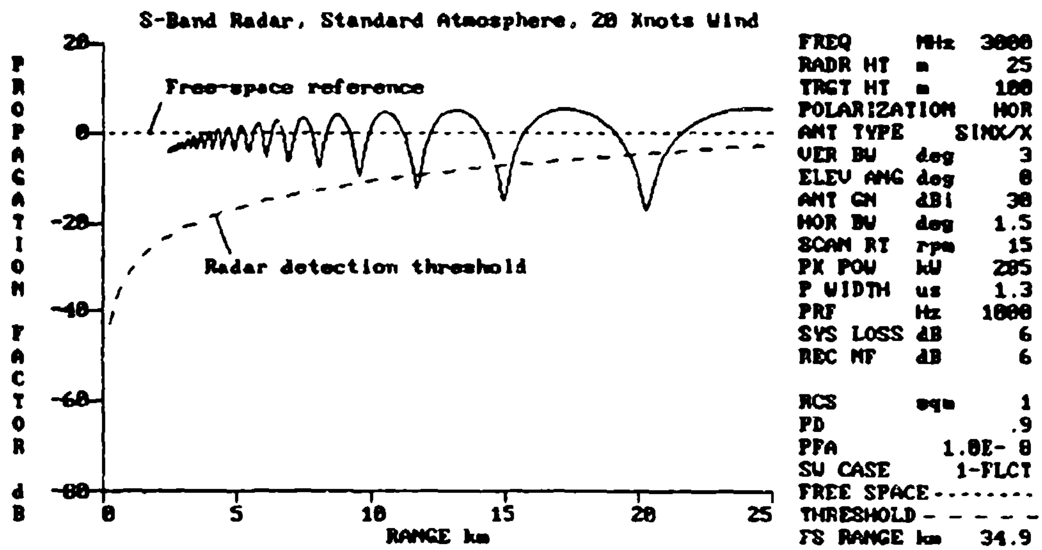


Figure 3-11: PROPR - Wind Speed Effects.

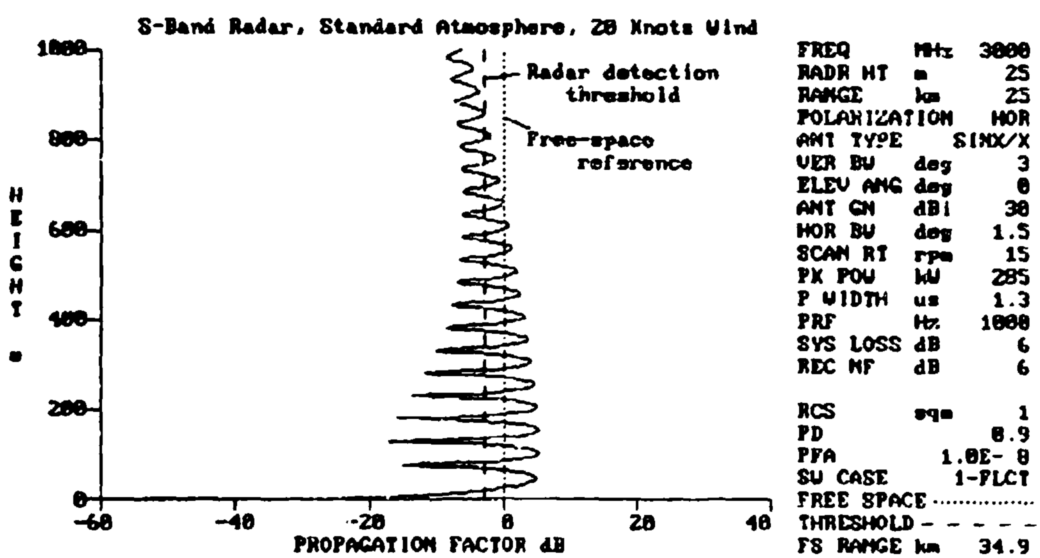


Figure 3-12: PROPH - Wind Speed Effects.

- An ESM intercept range study, parametric with evaporation duct height. The number on the propagation loss curve is the evaporation duct height.

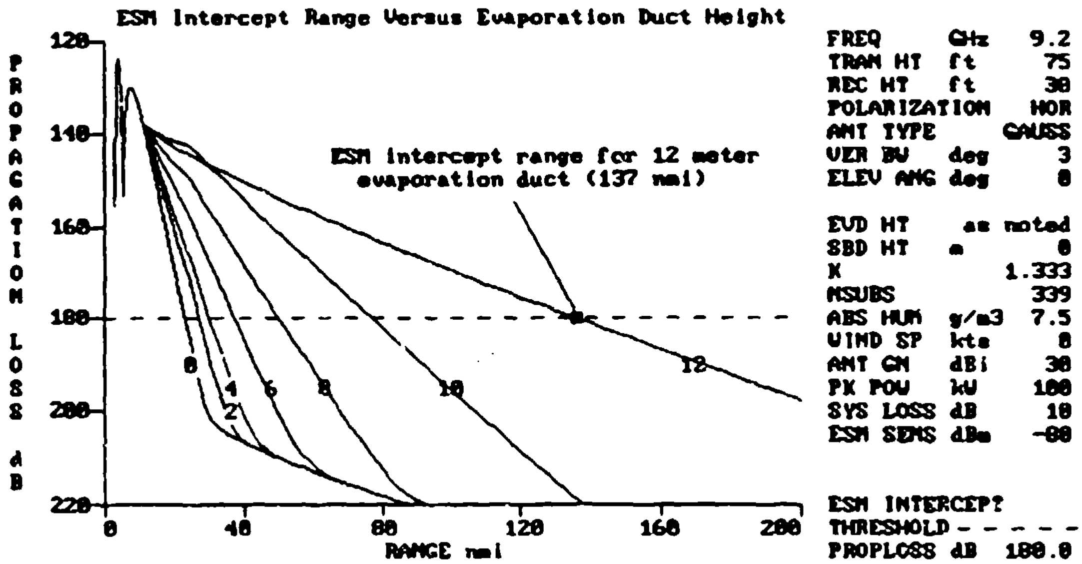


Figure 3-12: PROPR - Parametric Study in Evaporation Duct Height.

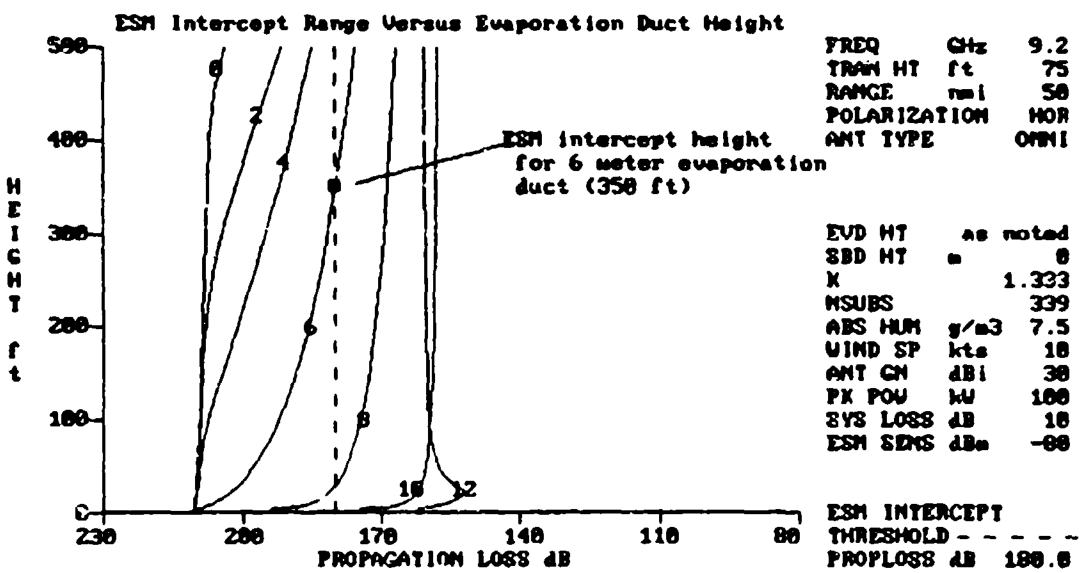


Figure 3-13: PROPH - Parametric Study in Evaporation Duct Height.

Like the COVER program, PROPR's and PROPH's primary intentions are to give engineers "relative" system performance under varying atmospheric conditions. But they too may be used in some tactical applications when care is exercised to ensure an appropriate threshold value.

Unlike COVER, however, PROPR may be used for surface-based, surface-search radars employed against surface targets. For a surface-based surface-search radar, a major consideration in performance assessment is the target's radar cross-section. The energy return from a ship target is distributed over the height interval from the waterline to the mast top, concentrated not from its smooth, large hull, but from its superstructure with its highly angled and complicated structure. In addition, the size of a ship target is such that its viewing angle becomes increasingly important with close ranges. For these radar cross-section issues, a ship is considered a distributed target. It must be remembered that such a distributed target is being represented as a point source target by the EREPS propagation model. While this assumption is valid for determining the greatest range of detection, it is increasingly less accurate with decreasing range, as the target becomes less of a point source.

In addition to the point source assumption, the target's height must be a single height. To establish the height, you may assume the target's entire radar cross-section is concentrated at a point approximately one-third the way up the superstructure. The superstructure for this purpose is that portion of the ship above the main deck including all major antennas.

RAYS

The RAYS program traces the paths, in height and range, of electromagnetic rays based upon a linearly segmented refractivity-versus-altitude profile(s), where the atmosphere's refractive structure is allowed to vary both in height and range. The ray tracing is accomplished using the small angle approximation to Snell's law.

For the range-independent use of RAYS, you may specify the vertical structure of the atmosphere by one of seven methods. For the range-dependent use of RAYS, you must specify the structure of the atmosphere external to the RAYS program and then enter the data into RAYS from an ASCII text file.

► To define the refractivity structure of the atmosphere.

1. Numerical Height Versus *M*- or *N*-Units

Height (ft)	M-units
0	342.8
223	351.4
416	359.5
725	378.9

This method allows you to construct a modified refractivity profile by entering heights (feet or meters) and corresponding *N*- or *M*-units.

2. Pressure, Temperature, and Humidity

P(mb)	Ta(°C)	Td(°C)
1008	15.1	13.4
1000	14.4	13.2
993	13.9	13.1
982	13.[illegible]	12.8

For this method, you enter pressure (millibars or hectopascals); temperature (F or C); and a humidity. The humidity may be either relative humidity (%), a dew point temperature (F or C), or dew point depression temperature (F or C). RAYS calculates the refractivity by equations 2 through 5 of chapter 2.

3. World Meteorological Organization Message

```
WMO message (UUBB part)
1700/ 99315 71183 12018
00008 15017 11000 14412
22993 13808 33982 13205
44972 20470 55962 21466
```

The World Meteorological Organization (WMO) defines a meteorological message as a message comprising a single meteorological bulletin. The WMO message is composed of five character figure groups divided into two parts labeled XXAA and XXBB where XX is replaced with TT for land stations and UU for ship stations. The XXAA section reports data for mandatory isobaric surfaces. The mandatory levels are isobaric surfaces of 1000, 850, 700, 500, 400, 300, 250, 200, 150, and 100 millibars (hectopascals). Section XXBB reports data for significant levels with respect to temperature and humidity. A significant level is defined as a level at which temperature and/or relative humidity data are sufficiently important, or unusual, to warrant the

attention of a forecaster (such as cloud bases or icing strata) or to allow for precise plotting of the radiosonde observation.

For RAYS, you enter the UUBB portion of the WMO message. Mandatory levels also may be significant but are occasionally left out of the significant level section. For this reason, it is advantageous to merge sections XXAA and XXBB (ensuring pressures remain decreasing from group to group). The reporting for ships differs only in the header symbology and position of reporting.

4. Evaporation Duct Calculations

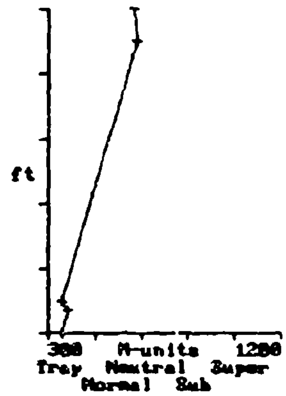
From the equation of N, a change in the atmosphere's moisture distribution without an accompanying temperature change can lead to a change in refractivity. The air in contact with the ocean's surface is saturated with water vapor. A few meters above the surface, the air is not usually saturated so there is a decrease of water vapor pressure from the surface to some value well above the surface. The rapid decrease of water vapor initially causes the modified refractivity, M, to decrease with height. At greater heights the water vapor distribution will cause M to reach a minimum and, therefore, again increase with height. The height at which M reaches a minimum defines the evaporation duct height.

```
 (Bulk met parameters)
SFC AIR TEMP °C      16
SEA-SFC TEMP °C      15
SFC REL HUMID %      70
SFC WIND SPD  kts    10
MODIFY JESKE PROF     N

 (Height & stability)
EVAP DUCT HT  m    12.2
MONIN-OBUKHOV   -0.0955
RICHARDSON #    -0.0771
```

This method constructs a modified refractivity profile by your specification of one of two data sets. The first set is the bulk meteorological parameters necessary for calculation of the evaporation duct height, i.e., surface wind speed, air temperature, sea-surface temperature, and relative humidity. The calculated evaporation duct may then be used directly or modified to account for possible observational errors in the meteorological values. The second set is the evaporation duct height and a stability parameter, either the Monin-Obukhov length or the Richardson number.

5. Draw Profile Graphically



This method allows you to construct a modified refractivity profile by digitizing points upon a height versus *N/M*-unit graph using a cross hair or mouse. As you digitize points, they are connected with a line colored appropriately for the calculated *N/M*-unit gradient between the points.

6. Profile Characteristics

```
Surface (low elv) duct
DUCT TOP         ft   1010
LAYER THICK            200
BLW LYR GRD M/kft       36
IN LAYER GRAD         -125

Elv layer (or duct)
LAYER TOP            10000
LAYER BOTTOM          9000
IN LAYER GRAD          -10
BELOW LAYER GRAD        36

Elv layer (or duct)
LAYER TOP            18000
LAYER BOTTOM         17000
IN LAYER GRAD          -10
BELOW LAYER GRAD        36

PROFILE TOP          20000
GRAD TO TOP             36
```

This method allows you to specify refractivity feature characteristics. You may define up to three features (ducts or layers) and the *N/M*-unit gradient between them. The first feature may be a surface duct created from a surface trapping layer, a surface-based duct created from an elevated trapping layer, or a low elevated duct. You define its top height, the thickness of the trapping layer, the *N/M*-unit gradient from the surface to the bottom of the trapping layer, and the trapping layer's *N/M*-unit gradient. To create the surface duct, you must set the duct's top and trapping layer thickness to the same value. The below layer gradient field will then become unavailable. To regain the use of this field, you must set the thickness value to something less than the duct's top.

The second and third features are layers. You define their top and bottom heights, the *N/M*-unit gradient within the layer, and the *N/M*-unit gradient below the layer. Entering a trapping gradient within the layer, creates an elevated duct. If the trapping gradient is sufficiently severe, you can create a surface-based duct that encompasses all lower features. Input bounds checking prevents one layer from being super-imposed upon another. Therefore, it may be necessary to negate one layer to change the bounds limits of another.

7. **Environmental File**

```
Profile Description
FILE NAME ?
```

For the range-dependent use of RAYS, the radio-refractivity (*N/M*-units versus height) or meteorological field data (pressure, temperature, and humidity) is read from an ASCII text file. Entering a question mark in the file name field will open the file-handling window. See the on-line help on the TITLE page and the environmental file description in chapter 5 for a complete discussion of the file's and the profile's structure. While this method is the only one available for the range-dependent atmosphere, it may also be used with a range-independent atmosphere. The file and profile structure remains the same.

Using the raytrace diagram

RAYS is only a simple raytrace based upon Snell's law. It is independent of any EM system parameters. It does not compute propagation loss or propagation factor along the ray path. It does not indicate any signal enhancement or degradation due to the waves' phase at ray intersections. Multipath propagation due to sea-surface reflection is not considered. Therefore, multipath interference is implied only in a qualitative sense.

The following figures illustrate how you may use the raytrace diagram. Various display options are shown in addition to the customized labeling features of EREPS.

- You may examine the ray paths for EM energy trapped within a surface-based duct. In particular, you may see which path angles are not trapped within the duct or which angles cause the ray path to reflect from the earth's surface and, again, escape being trapped within the duct. In addition, the skip-zone of a surface-based duct is readily visible.

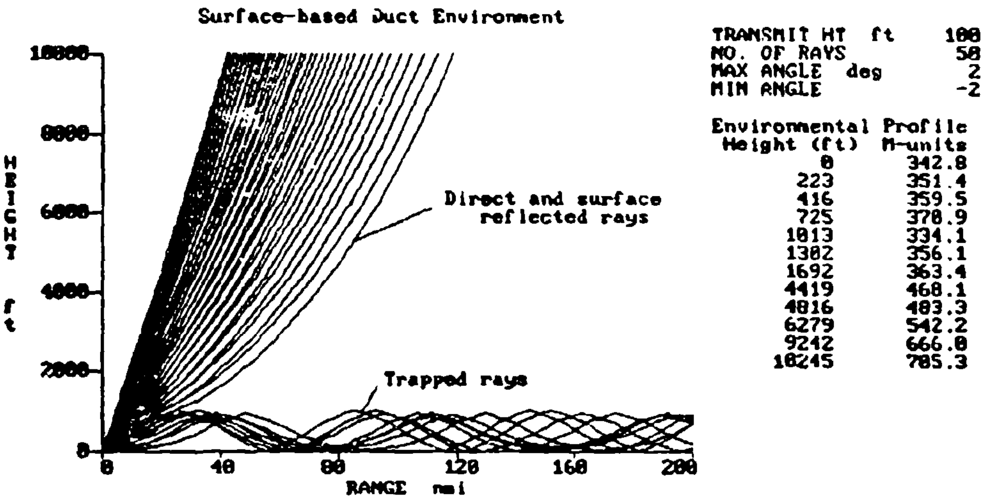


Figure 3-14: RAYS Display.

- Height-finding radars determine altitude based upon a standard atmosphere ray path. For nonstandard refractive conditions, the target's calculated altitude will be in error. By selecting the *ALTITUDE ERROR* option, the ray paths will be drawn with the nonstandard conditions but will be color-coded according to the altitude errors calculated along the path. The error is simply the difference in actual altitude and the altitude the ray would have under standard propagation conditions.

You may specify the error increments with the *ALT ERROR INC* value. After the raytrace is drawn, an altitude error legend is shown. By using a mouse or the arrow key, you may move the legend anywhere on the screen.

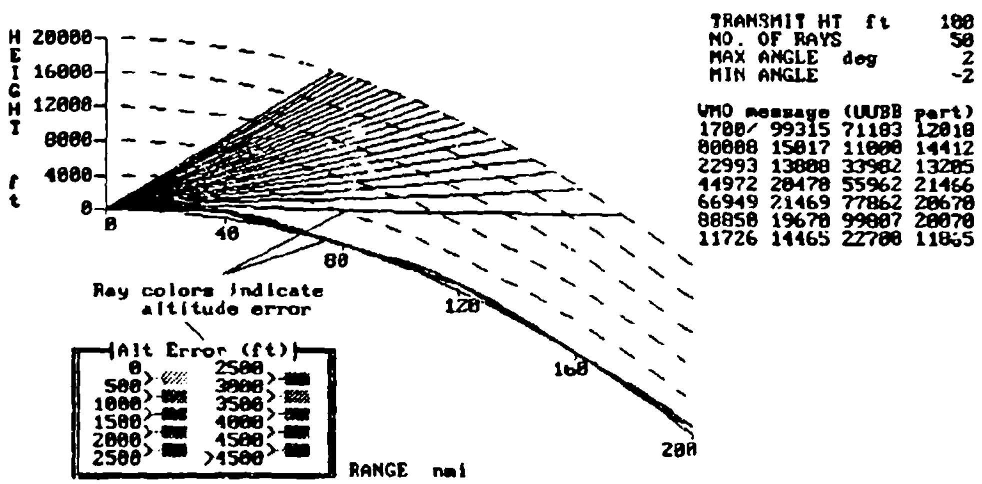


Figure 3-15: RAYS Height Error Display.

• RAYS is the only EREPS program that allows an airborne transmitter. By selecting different transmitter heights, the effects of elevated nonstandard layers may be examined.

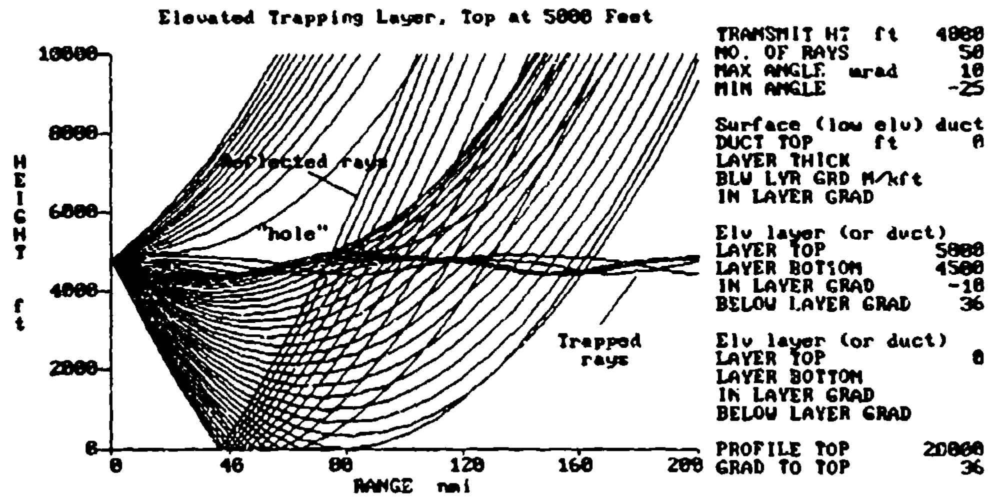


Figure 3-16: RAYS Airborne Transmitter Display.

The radar "hole" associated with an elevated duct is the only true "hole" in ray theory. That is, there is no ray, excluding a surface-reflected ray, that can be traced into the hole region. In a practical sense, the energy level within the hole area is due to physical optics processes, atmospheric scattering, and surface reflection (if any) and not by direct path wave propagation into the area.

• At air mass and ocean/land mass boundaries, the refractive structure of the atmosphere is not always homogeneous. By using the environmental input method 7 (read from a file), you may define a varying horizontal structure. For example, in the southern California area, it is not uncommon to have a Santa Ana wind condition create a surface-based duct along the coast line. Westward, the trapping layer rises to create an elevated duct under the tradewind inversion of the Pacific high-pressure system.

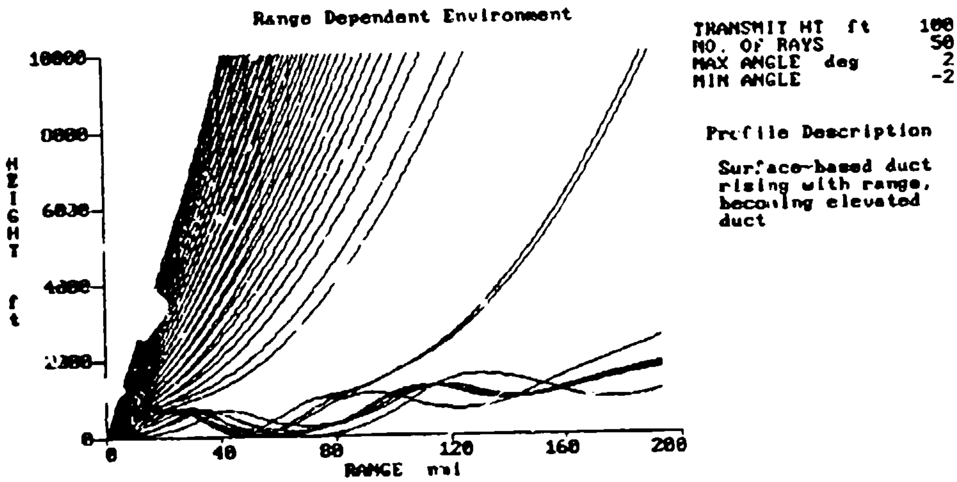


Figure 3-17: RAYS Range-Dependent Environment Display.

The option to save a modified refractivity profile that RAYS creates from the data you enter is particularly important. The saved file format is that required by NRaD's RPO propagation model. You may, therefore, use the RAYS program to create environmental input files for RPO. Since RAYS will only create and save one profile at a time, you may only use the saved file to run RPO in the range-independent mode. If you desire range dependency, you must first create the profiles individually and, then, external to EREPS, assemble them in the format prescribed for an RPO environmental file. This format is completely described in the on-line help and within chapter 5, environmental file.

SDS

The SDS program displays an annual climatological surface duct summary for one or more Marsden squares. The statistics displayed within SDS are derived from two meteorological data bases; the Radiosonde Data Analysis II assembled by the GTE Sylvania Corporation and the DUCT63 assembled by the National Climatic Data Center. The GTE Sylvania analysis is based on approximately 3 million worldwide radiosonde soundings taken during a 5-year period, from 1966 to 1969 and 1973 to 1974. The DUCT63 analysis is a 15-year subset of over 150 years of worldwide surface meteorological observations obtained from ship logs, ship weather reporting forms, published observations, automatic buoys, etc.

These data may be used in the other EREPS programs as input values (indicated by italics). These data are:

Percent occurrence histogram of evaporation duct heights
Evaporation duct height *EVD HT*
Surface wind speed *WIND SP* or *SFC WIND SPD*
Number of observations
Percent occurrence of surface-based ducts
Surface-based duct height *SBD HT*
Surface N-unit value *NSUBS*
Effective earth radius factor *K*

The entire world is divided into 10-degree by 10-degree squares called Marsden squares. Marsden squares outlined by the grid contain evaporation duct data. Evaporation duct data are not available for Marsden squares outside the grid. Surface-based duct data are available from radiosonde stations inside or outside the grid. The plus signs, "+", on the map represent the location of coastal and island radiosonde stations. Elsewhere in the SDS program, radiosonde stations are referenced by their name, latitude and longitude, and World Meteorological Organization (WMO) block/station identifier.

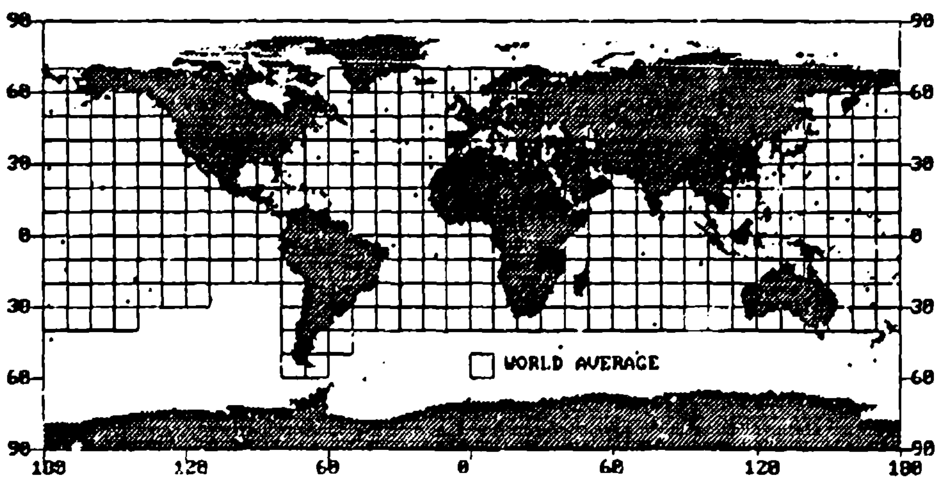


Figure 3-18: SDS World Map.

▶ **To select a Marsden square.**

1. Move the cross hair to the desired Marsden square.

2. Click the left mouse button or press the F4, (Select), key.

For reference, each selected square is highlighted in color. Marsden square number 142 is shown selected on the map above.

▶ **To remove a Marsden square.**

1. Move the cross hair to the desired Marsden square.

2. Click the right mouse button or press the F5, (Remove), key.

A single square or combination of squares may be selected or removed. Marsden square 515 is designated as a *WORLD AVERAGE*. Choosing this square will unselect all previously selected squares and provide a world average climatology. When a Marsden square is selected, all radiosonde stations within the square are also selected. When all desired squares are selected, press the F10 key to see the climatology. Surface-based duct climatology for an individual radiosonde station may be selected from the SUMMARY mode.

If you select more than one Marsden square, you CANNOT access an individual radiosonde station. Therefore, we recommend you select only one Marsden square if you are interested in surface-based duct climatology.

From the SUMMARY mode, you may display the individual radiosonde stations within the selected Marsden square by pressing the F4 key. Directions for selecting and unselecting a station are shown on the screen.

```
RADIOSONDE STATIONS IN MAR^DEN SQUARE: 142

   WMO ID   LAT      LON                RADIOSONDE STATION NAME
   ------  -------  -------   ----------------------------------------------
[*] 16754 35.33 N  25.18 E   HERAKLION CRETE, GREECE
[ ] 62062 32.10 N  24.00 E   TOBRUK, LIBYA
[ ] 16716 37.90 N  23.73 E   ATHINAI/HELLINIKON, GREECE
[ ] 17220 38.43 N  27.17 E   IZMIR, TURKEY
[ ] 62306 31.32 N  27.22 E   MERSA MATRUH, UNITED ARAB REPUBLIC (EGYPT)
[ ] 62053 32.00 N  20.27 E   BENGHAZI/BENINA, LIBYA

   Using ↑, ↓ or mouse, place crosshair over station.
   Press <spac bar>, F4 key, or left mouse button to select
   Press <space bar>, F5 key, or right mouse button to remove

                                                              1 SELECTED
F1 HELP F2:KEYS  F3:MAP   F4:SELECT F5:REMOVE                F10:SUMMARY
```

Figure 3-19: SDS Radiosonde Station Listing.

Averaged radiosonde data may be extremely misleading, depending upon the Marsden squares and the number of radiosonde stations within those squares. For example, the percent occurrence of surface-based ducts from an island radiosonde station such as Lihue, Kauai, Hawaii (Marsden square 88) and a coastal radiosonde station such as Vandenberg Air Force Base (Marsden square 121) are, meteorologically speaking, completely independent. Even the stations of Oakland, California, and Vandenberg AFB, which are within the same Marsden square, are still meteorologically independent. For this reason, a surface-based duct "averaged" from radiosonde stations in two or more squares, or even two or more stations within a single square may be meaningless. We do not recommend you average two or more stations unless they are in extreme proximity to each other.

Using the SDS program

The following illustrates how PROPR and SDS may be used together to assess statistical propagation performance. The example is based on a propagation experiment

performed between the Greek Islands of Naxos and Mykonos in 1972 and reported on by Richter and Hitney (1988).

On Naxos, transmitters at 1000 MHz (L-band), 3000 MHz (S-band), and 9600 MHz (X-band) were located 4.8 meters above mean sea level (msl). Also a transmitter at 18,000 MHz (Ku-band) was located 4.5 meters above msl. Receiving antennas were positioned at Mykonos for each frequency, 19.2 meters above msl for L-, S-, and X-bands and 17.8 meters above msl for Ku-band. The range separation was 35.2 kilometers, corresponding to a somewhat over-the-horizon propagation path. Horizontal polarization was used at all four frequencies. Propagation loss was measured for four 3-week periods in February, April, August, and November, except for Ku-band, which was measured only during August and November. All data were averaged over a 5-minute period and recorded every 15 minutes, 24 hours per day.

The first step in using EREPS to assess propagation effects is to obtain the climatology for the Greek Islands area, Marsden square 142. The evaporation duct height distribution shows the evaporation ducting effects are quite strong.

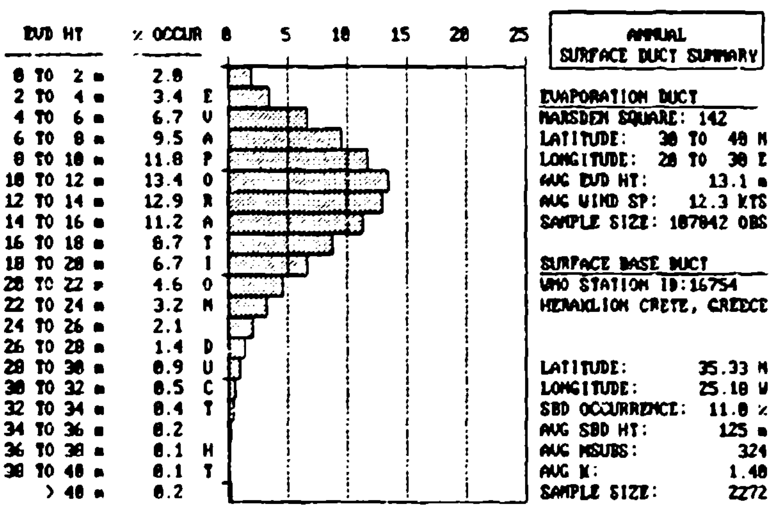


Figure 3-20: Evaporation Duct Histogram for Marsden Square 142.

The next step in this example is to use PROPR to investigate the sensitivity of propagation loss to environmental parameters. For standard atmospheric conditions, the X-band propagation loss is 174 dB for the geometries of the Greek Islands experiment.

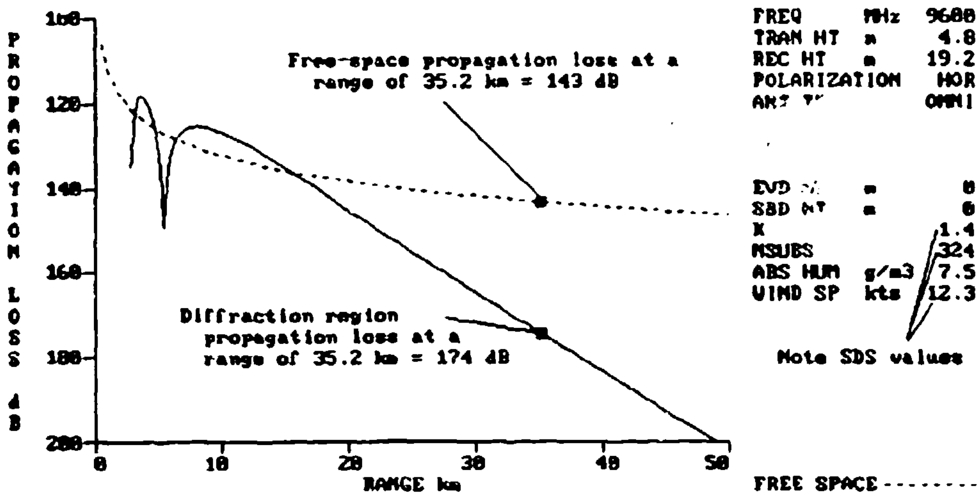


Figure 3-21: PROPR Display for Standard Atmospheric Conditions.

Note that while the XHAIR mode may be readily used to read the propagation loss values from the display, you may read values that are slightly different than someone else due to the display resolution In any case, readings should be accurate to about 0.5 dB, which is better than the probable overall accuracy of the models.

In this example, we are considering evaporation duct effects upon propagation. Thus, surface-based duct effects need to be examined to see if they will mask the results. PROPR can address the question, but for this example, RAYS is chosen to demonstrate surface-based ducting effects. Since SDS only provides the surface-based duct height (125 meters), a trapping layer thickness of 60 meters is arbitrarily chosen, and a trapping layer gradient is calculated to ensure the M-unit value at the surface is the same value at the duct's top. (RAYS assumes a surface value of 350 M-units. Since we are interested only in gradients,

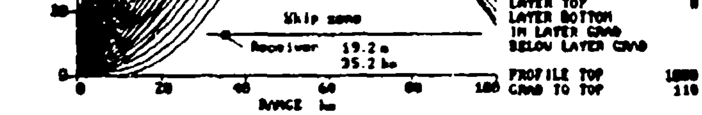


Figure 3-22: RAYS Display for Surface-based Duct Conditions.

the SDS value of 325 is inconsequential). That is, the necessary gradient to ensure a surface-based duct is formed with the specified geometry is calculated to be -127 *M*/km.

The skip-zone for this surface-based duct is quite evident. Also, the receiver is located well within the skip-zone. Therefore, you can conclude that surface-based ducts are not likely to affect the propagation loss in this example, even though such ducts will occur about 11 percent of the time in the Greek Islands area.

By using the overlay feature of PROPR and varying the evaporation duct height over the range of values indicated by SDS, you can easily show that propagation loss will vary substantially.

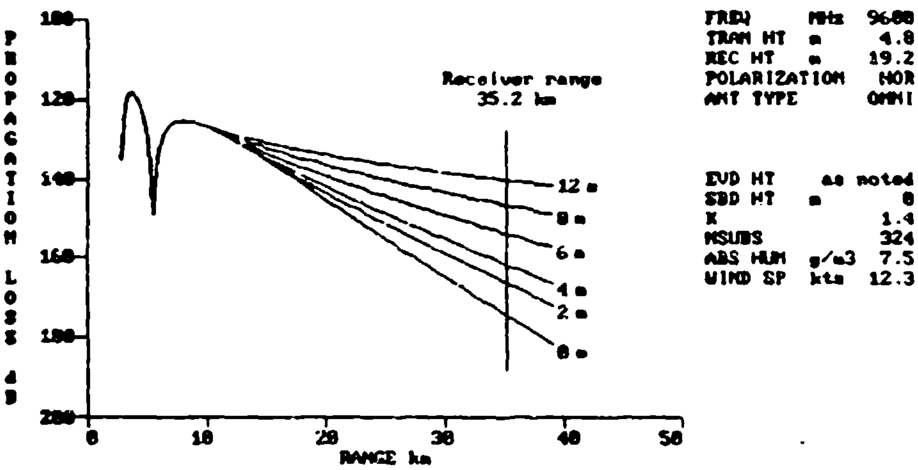


Figure 3-23: PROPR Display for Various Evaportion Duct Heights.

This is particularly true for the higher frequencies. Compiling the propagation loss values from PROPR versus evaporation duct height for the four frequencies and corresponding geometries (with * indicating duct heights beyond those recommended for use in PROPR) gives the following table.

Table 3-1: Pathloss Parametric in Evaporation Duct Height.

EVD Ht m	L-band	S-band	X-band	Ku-band
0	152.9	161.7	172.9	181.9
2	152.5	161.6	166.1	168.1
4	152.3	160.5	157.3	161.8
6	151.9	146.0	154.0	158.9
8	151.4	157.4	146.8	145.1
10	151.0	155.3	139.7	155.8
12	150.7	152.2	140.2	166.1*
14	150.4	148.4	143.5	172.6*
16	150.1	145.1	148.3*	172.6*
18	149.9	142.3	152.0*	172.6*
20	149.2	139.4	154.7*	172.6*
22	147.8	136.4	155.8*	172.6*
24	147.1	135.1	153.3*	172.6*
26	145.4	133.9	153.3*	172.6*
28	144.4	133.7	153.3*	172.6*
30	143.8	134.2	153.3*	172.6*
32	142.7	135.8*	153.3*	172.6*
34	141.2	137.0*	153.3*	172.6*
36	140.0	138.1*	153.3*	172.6*
38	139.0	139.1*	153.3*	172.6*
40	137.6	140.2*	153.3*	172.6*

Comparing the duct heights from table 3-1 with the duct height distribution of SDS indicates that EREPS can yield statistical assessments of propagation loss at L and S-bands, but will be questionable at X and Ku-bands.

The most useful statistical presentation is often the accumulated frequency distribution of propagation loss, which can be quite easily determined from SDS and the PROPR created table. For example, at L-band, propagation loss will always exceed 130 dB. Propagation loss greater than 140 dB occurs for duct heights less than 36 meters, which from SDS is 99.6 percent. Propagation loss greater than 150 dB corresponds to

duct heights less than 17 meters, or 75.2 percent. The accumulated frequency distributions thus determined are presented in table 3-2 for all four frequency bands. Also shown are the observed distributions as given by Richter and Hitney (1988).

Table 3-2: Observed and Predicted Path Loss.

Loss dB	L-band		S-band		X-band		Ku-band	
	EREPS	OBS	EREPS	OBS	EREPS	OBS	EREPS	OBS
120	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
130	100.0	95.8	100.0	80.6	100.0	94.3	100.0	100.0
140	99.6	89.5	84.6	65.3	83.6	74.1	100.0	98.9
150	75.2	64.5	40.1	39.3	41.6	38.5	81.3	70.5
160	0.0	9.5	8.8	3.9	7.1	4.7	64.5	27.3
170	0.0	0.0	0.0	0.0	1.0	0.9	48.8	7.1
180	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.8
190	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1

Examining the accumulated frequency distribution table shows that L-, S-, and X-band calculations are in reasonably good agreement with the observations, but Ku-band calculations indicate substantially higher propagation loss values than were observed. This disagreement is due to the frequent occurrence of duct heights in Marsden Square 142 that are beyond the recommended limits of EREPS at Ku-band. Note that X-band agrees quite well in spite of some duct heights occurring beyond the recommended limit. For applications in other areas where duct heights are predominantly low, such as in the North Atlantic Ocean, the EREPS assessments would prove to be good even at the highest frequencies.

There is a substantial reduction in propagation loss attributable to the evaporation duct when compared to diffraction levels without an evaporation duct. For example, the PROPR diagram under standard atmospheric conditions shown above indicates that X-band diffraction propagation loss is 174 dB and free-space propagation loss is 143 dB. Interpolation from the accumulated frequency distribution table shows the propagation loss exceeded 50 percent of the time is 148 dB. Thus, the evaporation duct has resulted in a signal strength improvement of 25 dB over diffraction with the median observed (or calculated) propagation loss much closer to free space than to diffraction.

You should note that similar methods as those used in this example may be applied to maximum detection, communication, or ESM ranges. You would employ PROPR to determine maximum range versus duct height and then use the duct height distributions from SDS to compute distributions of maximum range. In addition, PROPR or PROPH could be used to estimate frequency distributions of propagation factor or signal-to-noise ratio over a particular path.

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The EREPS Screen

Modes, Pages, and Fields

All of the EREPS programs are organized into sections called *MODES*. These modes allow you to enter, edit, or display data, or customize the EREPS program itself. The current mode name appears at the top left corner of the screen. Most modes are common between EREPS programs and, as such, retain a common name and behavior. Within any particular mode, screen prompts will direct you through the mode's function. A special function key bar at the bottom of the screen shows the modes or other options available to you. To select a mode, press its function key (F1 through F10) or point to the key's text and click the left mouse button. On-line help is available in all modes by pressing the F1 key.

Each screen of a mode is called a *PAGE* and each individual piece of input data is located on the page within a *FIELD*. Any units for the field are usually to the left of the field. For fields arranged in a column, any units are at the top of the column. While most modes will have only one page, some will have more. For example, PROPR and PROPH display option 3 and COVER display option 2 have additional EM system fields on a second page. Press the PAGE UP or PAGE DOWN key to move between pages.

Data Input

► **To enter or edit a data field.**

A highlight bar shows the current field and any units. A plain language prompt, input limits, and units appropriate for the data show on the top line of the screen. To input or edit a field, highlight the desired field, then type a new value. To highlight the field:

1. Press the TAB, SHIFT TAB, ←, →, ↑, ↓, or ENTER key.

or

2. Point to the field and click the left mouse button.

Before any changes are made to the field, the highlight is in yellow. While highlighted, the DELETE key will erase the contents of the field. Once a change is made to the field, the highlight will disapperar. The ← and → keys will move the cursor to the left and right within the field. The DELETE key will erase only the character under the cursor. In most cases, it is not necessary to press the ENTER key before moving to another field or pressing a special function key.

You should note that pressing an arrow key will not always move you across the screen in a constant row or column direction. For example, the ↑ key will move you to the closest field in the upward direction only. This field may be at a column location considerably different than the current field's column location. For this reason, using the TAB key or mouse may be, at times, more convenient for moving between fields.

Default Values and Limits

A default value and appropriate unit is supplied for each field. Each value has a recommended validity range. If you exceed the recommended limits, a warning message is given. For most values, however, you have complete control of the data you enter by simultaneously pressing the CTRL and ENTER keys.

STOP A value outside of the valid range may yield erroneous **BUT NOT NECESSARILY OBVIOUSLY WRONG** results, may cause the program to abort with a runtime error, may cause loss of computer memory, or may cause some other undesirable consequence. You are encouraged to adhere to the recommended limits when changing a value.

Units

All allowable units are preprogrammed, and you may not deviate from them. Units (and some values) may be "toggled" by pressing the SPACE BAR, by typing the first letter of the desired unit, or by clicking the right mouse but on. While the units on the graphic ordinate and abscissa will not be highlighted as are the other units, they still may be toggled when the associated maximum height, range, or loss value field is highlighted.

When you toggle units, the value is NOT converted to the new units. To change units AND convert the value, simultaneously press the CTRL key and the SPACE BAR. More than one field may be "tied" to a particular unit. Converting such a field will convert ALL fields tied to that unit. For example, in the RAYS program, converting ANY dew point temperature from degrees C to degrees F will also convert ALL other dew point temperature values in addition to ALL the air temperature values. For environmental profile fields, changing only the units will cause the profile to become a whole new profile. By changing units and converting the values, the profile remains the same.

When values are converted, they are also rounded to fit within the field. If a number is to large for the field, precision is lost. Converting the value again could compound the rounding error. Therefore, converting back to the original units may not convert the value back to its original value. **USE THE CONVERT UTILITY WITH CARE!!**

TITLE Mode

The TITLE mode provides introductory information about the particular EREPS program. Our address and telephone numbers are shown together with the program name and revision date. A short listing of program features is given in addition to major propagation model considerations. The on-line help of the TITLE mode gives general program operation guidelines and any special cautions about the program.

```
        Engineer's Refractive Effects Prediction System (EREPS)
              Program:PROPR  Version:3.0  30 November 1993

MANUFACTURE, USE, OR SALE OF THIS PROGRAM COVERED BY  U.S. PATENT 4,125,893
          NAVAL COMMAND, CONTROL AND OCEAN SURVEILLANCE CENTER
   NCCOSC RDTE DIV 543     53170 WOODWARD ROAD     SAN DIEGO CA 92152-7385
 Com: 619-553-1424  DSN: 553-1424  Fax: 619-553-1417  email: 5430nosc.mil

Use: Calculate and display propagation loss, propagation factor, or radar
     signal-to-noise ratio in dB versus range format.

Propagation models used:               User options:
  1. Optical interference                1. Easily edit all input parameters.
  2. Diffraction                         2. Overlay plots for direct comparison.
  3. Evaporation ducts                   3. Manage user data files.
  4. Surface-based ducts                 4. Customize graphic display for reports
  5. Water-vapor absorption              5. Full mouse ( ) support.
  6. Tropospheric scatter                6. Specify or compute system thresholds
  7. GIT/NOSC sea clutter                   as dB value or free-space range.
                                         7. Read dB values/ranges via crosshair

   Press <F3> key to quit, <F1> key for Help, or any other key to continue.

F1:HELP       F3:QUIT
```

Figure 4-1: PROPR TITLE Mode Page.

INIT Mode

From the INIT mode, you may select major program options such as display quantities, environmental input methods, propagation model choices, and graphic appearance options.

By selecting from the special function keys, you may return to the TITLE mode (F3), continue to enter supplemental data (F4), access pop-up menus to customize the program or perform other activities (F7 and F8), or produce a display (F10). Choosing PLOT without first choosing EDIT will produce a display using EREPS program defaults for all parameters found on the EDIT mode page(s). Allowing a PLOT directly from the INIT mode is primarily for program demonstration purposes. Should PLOT be chosen after returning to the INIT mode from the EDIT mode, parameters you entered on the EDIT mode page(s) will generally still be effective.

```
INIT MODE Display option (1,2,3,4)
                                        PROPR

Select one of the following displays:

   1 - PROPAGATION LOSS or PROPAGATION FACTOR vs. RANGE with
       up to 4 user defined thresholds.
   2 - PROPAGATION LOSS or PROPAGATION FACTOR vs. RANGE with
       one threshold based on ESM parameters.
   3 - PROPAGATION LOSS or PROPAGATION FACTOR vs. RANGE with
       one threshold based on radar parameters.
   4 - RADAR SIGNAL-TO-NOISE vs. RANGE.

   DISPLAY OPTION       0
   PROPAGATION MODEL    INTERNAL
   VERTICAL AXIS        L-PROPAGATION LOSS dB

   MAXIMUM RANGE    nmi 100

   NUMBER OF LOBES      2
   CLUTTER TYPE
   RADAR CALCS

F1:HELP   F3:TITLE F4:EDIT      F7:ATTRIB F8:OPTION        F10:PLOT
```

Figure 4-2: PROPR INIT Mode Page.

Of particular interest is the *PROPAGATION MODEL* prompt for the PROPR, PROPH, and COVER programs. Rather than using the EM propagation models internal to the EREPS programs to compute propagaton loss, precomputed loss values may be read from a binary data file. There are several programs that can generate propagation loss versus height and range data as output. Their output could be formatted as described in chapter 5, such that the loss data are readable by EREPS. One such program is NRaD's RPO program. By responding to the *PROPAGATION MODEL* prompt with *INTERNAL*, the EREPS models will be used to produce the desired graphic. Responding with *BINARY* will cause EREPS to read the RPO binary data file and display it in the fashion indicated by the EREPS Display option.

EDIT Mode

The EDIT modes serves as the primary data entry/edit point. While most EDIT modes will have only one page, some will have two. For example, PROPR and PROPH display option 3 and COVER display option 2 have additional EM system fields on a second page. Press the PAGE UP or PAGE DOWN key to move between pages. A highlight bar will show the field (and any units) currently in use. The parameter values and units

shown in these figures are EREPS program defaults. The following figure is page 2 of the PROPR EDIT mode.

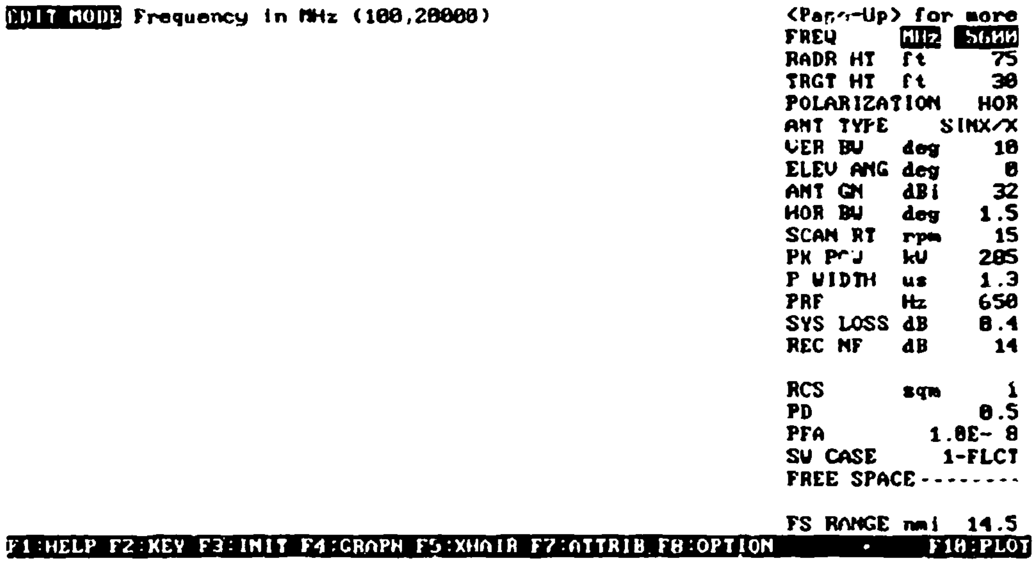

Figure 4-3: PROPR EDIT Mode Page.

By selecting from the special function keys, you may obtain help (F1); remove the special function key and mode label from the screen while making presentation slides or paper copies of the screen (F2); return to the INIT mode to change input options (F3); alter most display parameters from the GRAPH mode (F4); evoke a cross hair (XHAIR mode) so you may put your own text and lines on the graphic (F5); access pop-up menus to customize the program or perform other activities (F7 and F8); or produce a graphic (F10). If a graphic is already displayed, an additional OVERLAY key (F9) will be available. The overlay feature superimposes a new graphic upon the existing graphic and allows for comparison studies. Should you change a parameter that makes an overlay impossible, for example, changing the display axis depiction, the overlay key will automatically turn off.

GRAPH Mode

The GRAPH mode allows you to change most parameters that were initially set on the INIT mode. While some additional parameters may be found on the GRAPH mode, it and the INIT mode pages are essentially equivalent. In the GRAPH mode however, any drawn graphic remains on the screen. Special function keys are identical for both the GRAPH and EDIT modes.

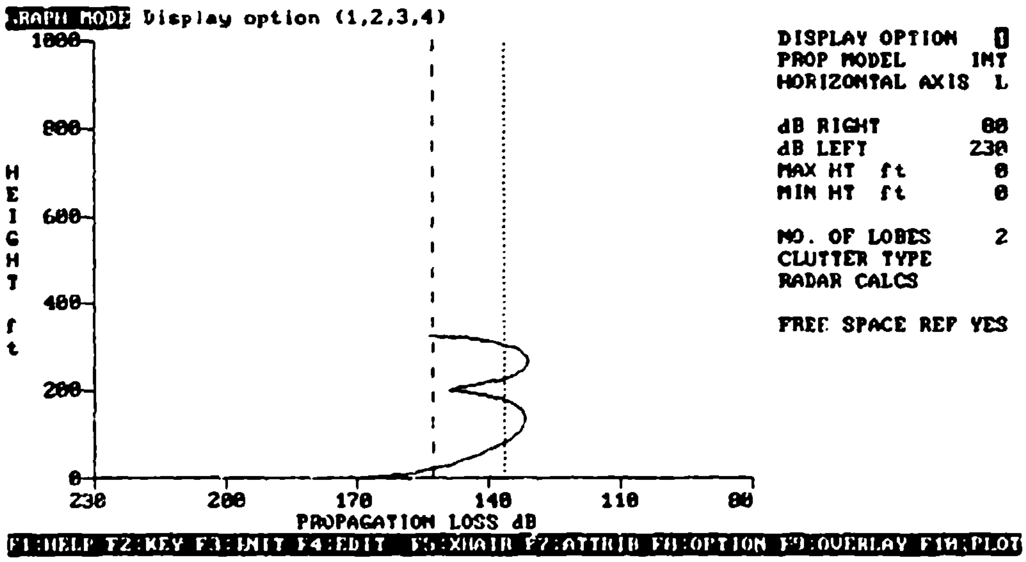

Figure 4-4: PROPH GRAPH Mode Page.

XHAIR Mode

The XHAIR (cross hair) mode allows you to place items, i.e., text, lines, and markers, on the screen. These items are useful when making overhead slides or hard copies for future display. The figure below illustrates the XHAIR mode being used by the RAYS program. The current cross hair position is shown at the bottom left of the screen. If no graphic is drawn, the location is given in screen row (or line) and column format. If a graphic is drawn, the location is given in units of the graphic, i.e., feet, nautical miles, etc., but only while the cross hair is within the plot area. If the F2 key is pressed, the

special function key bar will disappear but the cross hair will remain visible for your continued use. Moving it to the bottom of the screen will cause it to disappear. It will reappear again if it is moved away from the bottom.

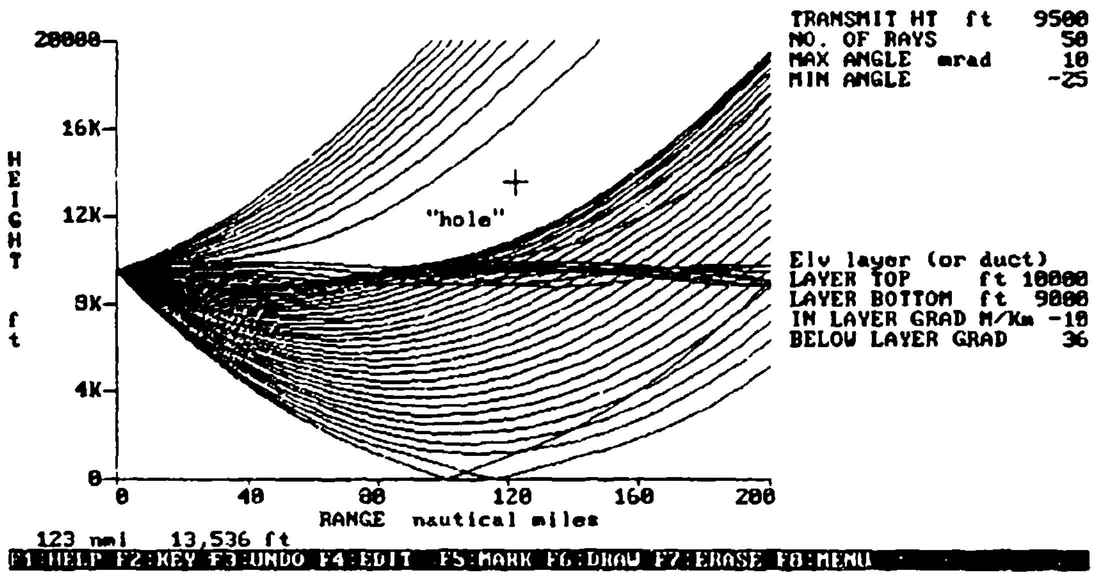

Figure 4-5: RAYS XHAIR Mode Page.

Each item has a set of attributes, i.e., color, style, etc. The attributes of all items may be set from the cross hair menu. To see the menu, press the F8 key or click on the MENU text. Refer to the on-line help within the cross hair menu for additional information.

The cross hair may be moved anywhere on the screen by moving the mouse or pressing the arrow keys. Using a mouse is highly recommended. When using the arrow keys, certain conventions apply. These are:

► **To use the Xhair Mode.**

1. **Moving the cross hair**

- Move the mouse.

- Press the arrow keys. When an arrow key is pressed, the cross hair moves in character cell increments (by row and column). Pressing the SHIFT+arrow keys moves the cross hair horizontally or vertically in pixel increments.

2. **Adding text**

- Move the cross hair to the desired location for the text.

- Type the text from the keyboard. The text will be registered on the row and column. For fine detail placement, select the "Border on" text style attribute from the MENU key. A small box outlining a character cell will be shown. Position the box and then type the text from the keyboard.

3. **Drawing a line**

- Move the cross hair to the line's starting point.

- Press the left button. Drag the cross hair to the line's ending point and then release the left button.

or

- Press the F6 key. Move the cross hair to the line's ending point and then press the F6 or (ENTER) key again. Clicking on the F6 key text will have no effect.

4. **Adding a mark**

- Move the cross hair to the mark's desired position.

- Click the left button.

or

- Press the F5 key. Pointing to and clicking on the F5 key text will have no effect.

5. **Erasing text, lines, and marks**

To erase items you put on the screen, you must first draw a box around all the items to erase. To do this,

- Move the cross hair to a point on the screen where you want the box to be "anchored."

- Press the right mouse button. Drag the mouse to expand a rubber-band box. When all the items to be erased are within the box, release the right mouse button.

or

- Press the F7 key. Move the cross hair until all items to be erased are within the rubber-band box. Then press the F7 (or ENTER) key again.

You may only erase items placed on the screen during your current cross hair session. Once you leave the XHAIR mode, you will not be able to erase any previously drawn items. The screen capture and print program, Pizazz Plus from Application Techniques, Inc., will cause the ERASE function to give unpredictable results. If this happens, return to the INIT mode and replot the graphic. The MS-DOS GRAPHICS.EXE program does not cause these problems.

As a reminder aid for the draw and erase functions, the cross hair symbols are unique for each function. These cross hairs are:

DRAW =  and ERASE = 

These cross hair symbols are also used within the RAYS program when entering an environmental profile graphically.

6. **Erasing everything you have added**

- Point to and click on the UNDO text.

or

- Press the F3 key.

MAP Mode

The entire world is divided into 10-degree by 10-degree squares called Marsden squares.

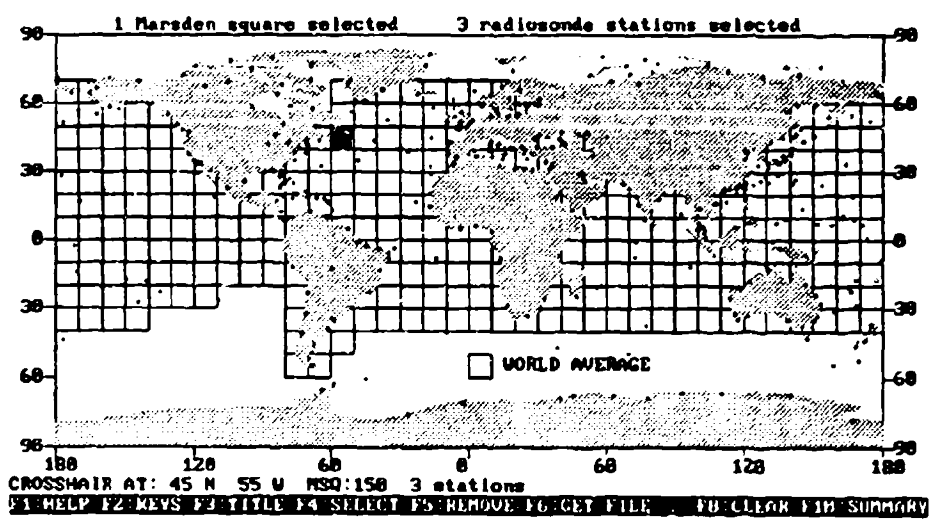

Figure 4-6: SDS MAP Mode Page.

Marsden squares outlined by the grid contain evaporation duct data. Evaporation duct data are not available for Marsden squares outside the grid. Surface-based duct data are available from radiosonde stations inside or outside the grid. The plus signs, "+", on the map represent the location of coastal and island radiosonde stations. Elsewhere in the

SDS program, radiosonde stations are referenced by their name, latitude and longitude, and World Meteorological Organization (WMO) block/station identifier.

SUMMARY Mode

The SUMMARY mode is an evaporation duct height histogram and surface-based duct climatology for the area selected from the MAP mode. You may display individual radiosonde station's surface-based duct climatology by pressing the F4 key or clicking on the CHOOSE UPPER AIR text. You may save the climatological data for all selected squares and a list of the squares by pressing the F7 key or clicking on the SAVE FILE text. As with the other EREPS programs, you may annotate the display using the XHAIR mode.

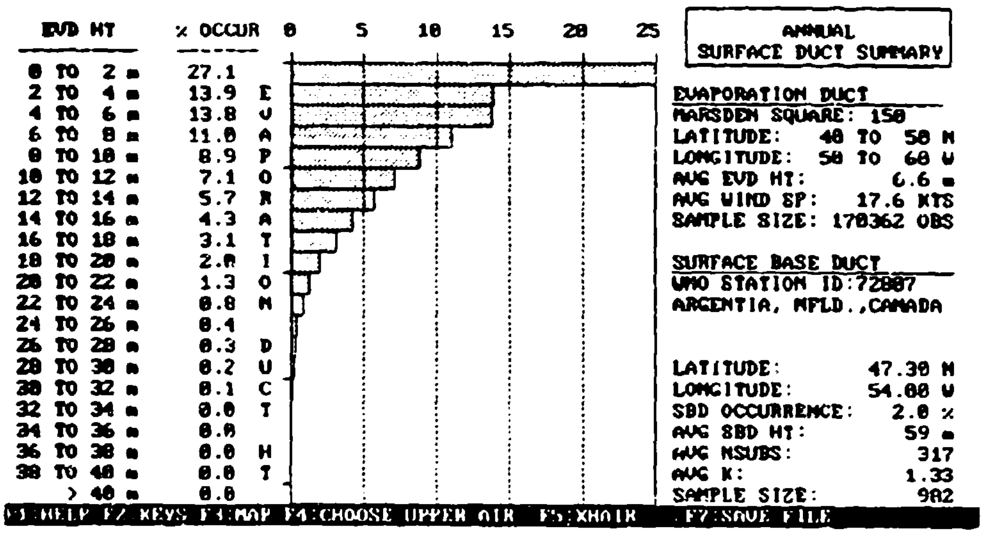

Figure 4-7: SDS SUMMARY Mode Page.

Menus

EREPS uses pop-up menus for choosing program options (the options menu), reading or saving EREPS support files (the file menu), and customizing colors, line and mark styles, and fill patterns (attribute, cross hair, and user data menus). The menus are

common between all the EREPS programs, as is the method for making a choice from a menu.

► **To make choice from a menu, use one of the following three methods.**

1. Highlight your choice with the arrow or TAB key, then press the ENTER key.

2. Press the "hot" key (colored differently), then press the ENTER key.

3. Point to your choice, then double click the left mouse button.

Options menu

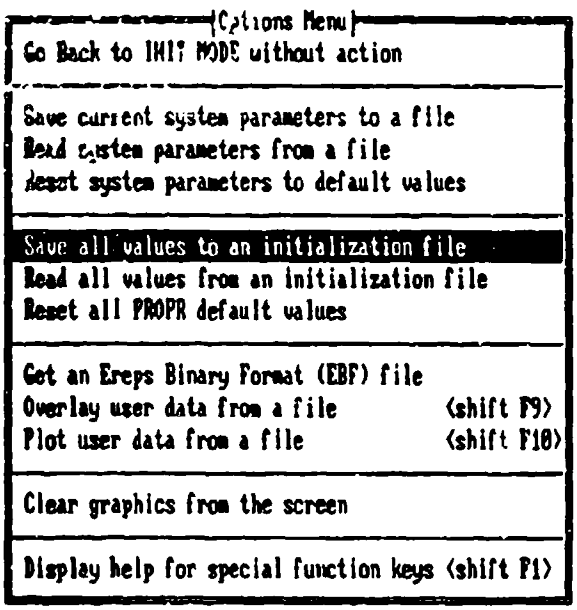

Figure 4-8: Options Menu.

With the options menu, you may save or restore program initialization parameters for customizing the EREPS program's start-up, save or restore EM system parameters or environmental inputs, restore default values for all of the EREPS input fields, and plot or overlay your own data upon an EREPS graphic. The options themselves should be self-explanatory from the menu, but each option does have its own detailed on-line help. See chapter 5 for a complete description of the EREPS support files.

Attributes menu

From the attribute menu, you may define colors, line styles, and fill patterns for various items within the EREPS programs. The menu is divided into two columns, one for items specific to the individual EREPS program (COVER, PROPR, etc.) and one for items used universally throughout all the EREPS programs.

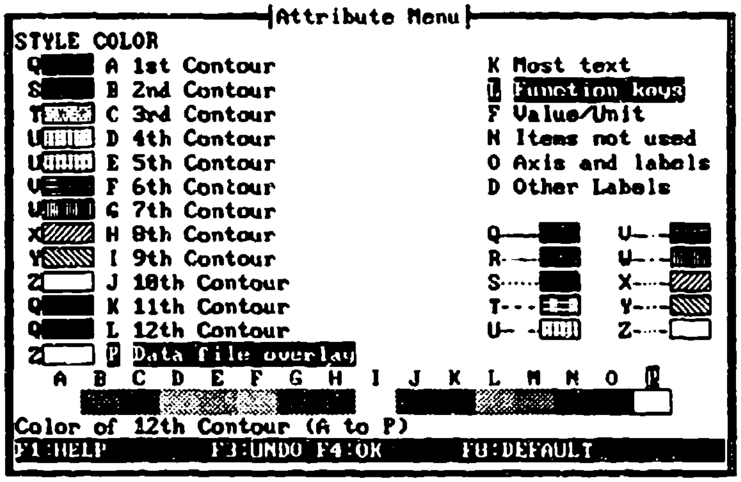

Figure 4-9: Attributes Menu.

► **To select and change an item's attribute.**

1. Highlight the item you want to change.

2. Point to and click on a color box, line style, or fill style box. To change the item's background color, point to and click the right mouse button on the color box.

or

3. Press the SPACE BAR or the letter key associated with the color or style you desire. To change the item's background color, press the SHIFT+SPACE BAR or the SHIFT+letter key.

STOP Caution should be exercised as you could render an item invisible if you select the same color for both foreground and background.

When you plot or overlay your own data on the graphic, a mark is placed at each data point within the scale of the graphic. If the line color is black (P), the marks will not be connected with a line. Otherwise, the marks will be connected with a line of the selected color and style. The mark's style and color may be defined on the user data menu displayed within the OPTIONS menu.

You may receive on-line help (F1 key), reset all colors, line styles, and fill patterns back to those when the attributes menu was opened (F3 key), or reset them back to the EREPS defaults (F8 key).

File menu

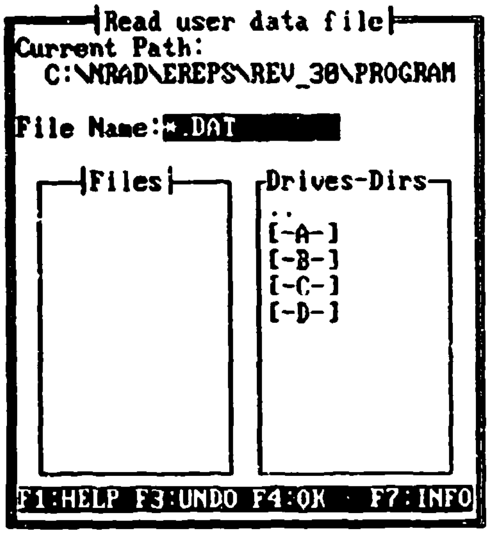

Figure 4-10: File Menu.

The file menu allows you to access the MS-DOS directory and file system for saving or getting any type of EREPS support file. The file menu is composed of three sub-windows and four special function keys. These sub-windows are the File Name, used for entering a specific file name; the Files, used to display all the files within the current directory; and the Drives/Dirs, used to display all directories and disk drives.

► **To enter or select a file.**

1. Highlight the File Name sub-window and type a file name.

or

2. Highlight a file, directory, or disk by pressing the ↑ or ↓ key or by clicking on the scroll bar at the sub-window's edge.

3. Press the ENTER or F4 key or double click the left mouse button to select the highlighted file. To select a directory or disk, press the ENTER key or single click the left mouse button. As the current directory or disk is changed, its MS-DOS path is displayed at the top of the file menu and its file contents are displayed in the Files sub-window.

You may also obtain on-line help, exit the menu without performing an action (F3 key), and obtain information about your disk (F7 key).

Cross Hair and User Data menu

The cross hair menu defines the attributes of various items you may use when you label and draw on the EREPS graphic. The USER DATA menu defines the attributes of marks and line when you overlay or plot your own data on an EREPS graphic. While the two menus appear identical, the USER DATA meru's scope is limited to just the mark and line style attributes.

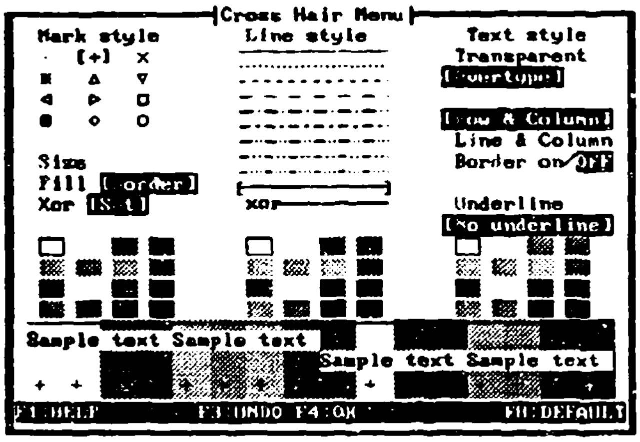

Figure 4-11: Cross Hair and User Data Menu.

The menu is divided into three columns, mark style, line style, and text style, each with an array of colored boxes under the column.

► **To choose an item and its attributes.**

1. Highlight the item from its column.

2. Highlight the desired color box beneath the item's column.

3. Press the ENTER or F4 key or point to and click on the OK text.

As you make choices, a sample result is displayed at the bottom of the menu. By clicking the right mouse button over a colored box, the background color will change. This is only an aid to visualize a particular mark, line, or text color upon a color other than black. Changing the menu's background colors has no effect upon any page's background color. The options under the each of the three columns are:

Mark style	Description
[ ]	Highlights the current choice.
Size	Changes the size of the mark.
Fill	Fills the interior of the mark with its color.
Border	Displays only the mark's outline.
Xor	Allows the display under the mark to show through.
Set	Does not allow display under the mark to show through.

Line style	
Xor	Allows the display under the line to show through. For this choice, only a solid line style is allowed.

Text style	
Transparent	Allows display under the text to show through.
Overtype	Does not allow display under the text to show through.
Row & Column	Prints the text to the nearest screen row and column.
Line & Column	Prints the text on the nearest line pixel and screen column.
Border	Displays a small box showing you the location of a character to be printed.
Underline	Displays the text with an underline.
No underline	Displays the text without an underline.

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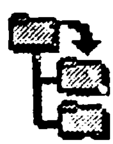
Support Files

EREPS Directory and Files

EREPS uses a number of specialized data files, most of which you create yourself with the programs' filing options. You have complete freedom to organize the EREPS programs and any data files on your floppy or hard disk. You may name directories and data files with any valid MS-DOS directory or file name.

Directory Structure



To help you with the program and data file organization, all EREPS programs recognize three directory types. All three types may be one directory. The EREPS program will "sense" the name(s) you give these directories. These directory types are:

- *HOME* directory

The current directory (the directory where you start the program) is referred to as the *HOME* directory. While the program is running, you always physically remain in your *HOME* directory. When the program ends, you will be in the directory you started from.

- *EREPS* directory

The directory containing the *.EXE and EREPS.HLP files is referred to as the *EREPS* directory. If your *HOME* and *EREPS* directories are different, the *EREPS* directory must be in your computer's PATH statement. Refer to your MS-DOS manual for information about the PATH statement and the AUTOEXEC.BAT file.

- *FILES* directory

The directory containing all the files you create or read from during the program's operation is referred to as the *FILES* directory. Unlike the *HOME* and *EREPS* directories that become fixed when the program starts, the *FILES* directory will change as you use it. The *FILES* directory is accessed from a file-handling window. The file-handling window

may be opened by entering a question mark, "?", for any file name. You may use separate *FILES* directories for your program, EM system, initialization, environmental, binary format, and data files.

You are completely free to use as many *FILES* directories as you wish. As a convenience, EREPS will "remember" the *FILES* directory path structure for each file type as you use it. For example, you have a number of EM system files in a directory called C:\EREPS\COVER\SYSTEMS. You have a number of EREPS binary format files in a directory called C:\EREPS\RPOFILES. When you start the COVER program, you read an EM system file to initialize all the system fields. Then you read an EREPS binary format file for plotting. The next time you want to read an EM system file, EREPS will begin its search in the SYSTEMS directory.

Support Data Files

The EREPS programs use a number of supporting data files, created by using the internal filing features of the program or by an ASCII text editor. You may name any file any valid MS-DOS file name. As an aid in avoiding file confusion, several default extensions are used for EREPS data files. These default extensions and a description of the file's contents are:

Extension	Use or contents
.INI	All EREPS program initialization data
.HLP	EREPS on-line help
.SYS	COVER, PROPR, and PROPH electromagnetic system data
.ENV	RAYS environmental data
.EBF	Propagation loss values in the EREPS binary format
.DAT	Your own data
.SDS	Climatology data for selected Marsden squares from SDS

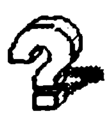
Initialization file

GO Upon starting each EREPS program, an initialization file containing your customized program configuration may be read. The

default file name is the name of the EREPS program with an extension of .INI, for example, COVER.INI or RAYS.INI. By default, when the program first starts, it will search your *HOME* directory for the *.INI file. If the file is not found in the *HOME* directory, the program will then search the *EREPS* directory for the *.INI file. If the default file is found, its contents will be used. If not, the normal EREPS internal default values will be used. If you specify a initialization file on the MS-DOS command line, an attempt to use the file will be made. If an error occurs, the normal EREPS default values will be used, even if a valid default *.INI file exists. You may specify different names for the initialization file. Thus, you may have several such files for your customized configuration. You may recall these values at any time with the OPTIONS menu. Remember, however, EREPS will automatically read the initialization file upon program startup ONLY if it has the default name and is located in *HOME* or *EREPS* directories.

While you may view and edit the initialization file with any ASCII text editor such as EDIT.EXE that is provided with MS-DOS, we recommend you SAVE and READ the contents of the file by using the Options Menu. The file structure is critical for proper program operation, and any error in reading the file may cause the EREPS program to abort.

On-line help file



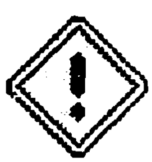
Every input parameter, menu item, program option, and special function key has its own on-line help. The help defines or describes the parameter and shows any associated units, limits, and default values. Special considerations, cautions, and proper parameter uses are also described. The on-line help is found within an ASCII help file used by all EREPS programs. You may print this file on a printer, but it is not necessary (nor particularly recommended). Each item of help in the file is "keyed" to a short prompt as seen on an EREPS page. The @ symbol is used to separate short prompts. For example, @TRAN HT@ identifies help for transmitter height. If you do choose to print this file, we suggest you first copy it, giving it a different name. Then using an ASCII text editor with the new file, remove the first 112 lines. These lines, which have no practical meaning for you, provide instructions to EREPS allowing help on a particular topic to be found quickly.

Electromagnetic system file

The PROPR, PROPH, and COVER programs require the input of many EM system parameters. Some examples are frequency, antenna polarization, transmitter power, etc. In performing system analyses, you may want to configure EREPS for a particular system to be used over and over again, either by the same program or another program. Once your particular parameter combination is entered, you may save it in a file. The contents of this file may then be recalled at any future date. For example, you may save a file defining your particular radar while using the PROPR program. You may then read the same file to initialize the COVER program with the same radar.

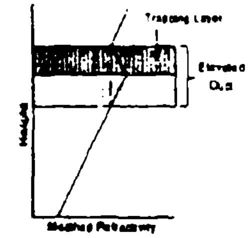
The system file is an ASCII text file, and like the initialization file, you may view and edit it with any ASCII text editor. Also like the initialization file, however, we recommend you SAVE and READ the contents of the file by using the options menu. The file structure is critical for proper program operation and any error in reading the file may cause the EREPS program to abort.

EREPS contains a utility program, CNVRT2X3.EXE, which converts your EREPS 2.x EM system files to the EREPS 3.0 format. To use this program at the MS-DOS command prompt, type *CNVRT2X3 filename*, where *filename* is the name of your EREPS 2.x EM system file. Wild card characters (? and *) are allowed. For example, if all your EM system files have an SYS extension, you would type *CNVRT2X3 *.SYS*. You may also type *CNVRT2X3 *.** and every file in the current directory is examined. If it is a system file that can be converted, you reveive a prompt for an action, either CONVERT, ALL, SKIP, or QUIT. Selecting ALL will convert all files without further prompts. If the file is not an EREPS EM system file, no action is taken. You may run this program with a -c option (*CNVRT2X3 -c filename*). The file is only examined and the findings are reported. No action is taken on the file.



The converted file will retain its name. If you want to keep the unconverted file, copy and save it with another name prior to the conversion.

Environmental file



Radio-refractivity (meteorological) field data for the raytrace program may be read from an ASCII text file. You may create the radio-refractivity (meteorological) field data file with any ASCII text editor. The format of the RAYS file is consistent with the RPO environmental files.

In creating a radio-refractivity (environment) field, a number of restrictions and conventions apply. These are:

- Radio-refractivity (meteorological) field restrictions.

A profile is defined as up to 50 couplets of height (feet or meters) and modified refractivity (*M*-units). Alternatively, a profile may be defined as up to 50 triplets of pressure (millibar or hectopascal), air temperature (F or C), and a humidity parameter. The humidity parameter may be relative humidity (%), dew point temperature (F or C), or dew point depression temperature (F or C). NOTE! RPO does not accept pressure, temperature, or humidity parameters.

The first numbered data point within a profile must correspond to a height of zero (pressure measured at the ground or sea level).

Within each profile, each numbered data point must correspond to a height greater than or equal to the previous height. Pressures must be consistently decreasing. Two pressures may never be equal.

The field may consist of up to 15 vertical piece-wise linear profiles at multiple arbitrary ranges. The range to the first profile should be zero. If not, the RAYS program assumes horizontal homogeneity of the first profile from its range to a range of zero.

Each profile must contain the same number of vertical data points and be specified such that each numbered data point corresponds to like-numbered points (i.e., features) in the other profiles.

- Key words and symbols (key words are case insensitive).

- Any line that begins with a # is a comment, ignored by RAYS.

@feet - signifies all heights are in units of feet.

@meters - signifies all heights are in units of meters. If a height keyword (@feet and @meters) is not present, meters are assumed.

@range - signifies a range from zero to the profile that follows. Following this key word is the actual range value. Following the range value is a range unit keyword. The unit keyword may be kilometers, km, or k; nautical miles, nmi, or n; statute miles, sm, or s. If the units keyword is not present, kilometers are assumed. Some examples are @range 39 sm, @RANGE 52, and @range 100 nautical miles.

@temp - signifies an assignment of temperature units. Following this key word is another key word, either Fahrenheit, F, f, Celsius, C, or c.

@humid - signifies a moisture parameter. Following this key word is another key word, either relative humidity or rel, dew point or point, or dew point depression or dep.

@label - signifies a label for the RPO program and is ignored by RAYS.

@wind - specifies the wind speed at range zero for the RPO program and is ignored by RAYS.

- Units may be mixed or changed anywhere between profiles but not within any single profile. The units apply to all following data until the units are changed again.

- Blank lines, spaces, data deliminators (i.e., a comma or spaces separating height from M-unit values), and any characters following the M-unit (or humidity) value are ignored.

STOP It is possible to make an error in the key word and still have the program accept the data. Erroneous results will occur that MAY NOT BE OBVIOUS. Ensure key words are used properly.

The following is a sample of a file that contains data for six profiles. These profiles were measured from a aircraft flying a saw-tooth pattern from San Diego, CA, to Guadalupe Isle, Mexico. The sample may be extracted from the help file (ereps.hlp) and used as an input file for the raytrace program. This profile is also provided as a "canned" environment for RAYS input method 7, read from a file.

```
# environmental input data for range dependent raytrace
@label San Diego to Guadeloupe Isle
@feet                         keyword for range in nautical miles
@range 0 nmi                  1st profile - nmi keyword for nautical miles
0.0,          337.000         1st layer - normal gradient
540.,         358.44          2nd layer - trapping gradient
803.407,      324.736         3rd layer - normal gradient
1217.17,      334.888         4th layer - trapping gradient
1231.0,       334.494         5th layer - subrefractive gradient
3500.0,       447.400

@range 39                     2nd height/M-unit profile
0.0,          337.000         1st layer - normal gradient
540.,         358.44          2nd layer - trapping gradient
803.407,      324.736         3rd layer - normal gradient
1217.17,      334.888         4th layer - trapping gradient
1231.0,       334.494         5th layer - subrefractive gradient
3500.0,       447.400

@range 85.5                   3rd height/M-unit profile
0.0,          337.169         1st layer - normal gradient
740.,         365.34          2nd layer - trapping gradient
1080.63,      343.702         3rd layer - normal gradient
1490.61,      356.039         4th layer - trapping gradient
1652.63,      351.889         5th layer - normal gradient
3500.0,       430.919
```

@range 125.		4th height/*M*-unit profile
0.0,	335.819	1st layer - normal gradient
1190.,	382.84	2nd layer - trapping gradient
1574.55,	357.962	3rd layer - normal gradient
1889.38,	371.111	4th layer - trapping gradient
2096.94,	371.011	5th layer - normal gradient
3500.0,	430.957	
@range 160.		5th height/*M*-unit profile
0.0,	333.676	1st layer - normal gradient
1145.0,	378.220	2nd layer - trapping gradient
2140.0,	370.715	3rd layer - subrefractive gradient
2584.38,	398.294	4th layer - superrefractive gradient
2923.08,	404.423	5th layer - normal gradient
3500.0,	429.802	
@range 193.		6th height/*M*-unit profile
0.0,	331.056	1st layer - normal gradient
1420.0,	382.920	2nd layer - superrefractive gradient
2387.5,	383.544	3rd layer - subrefractive gradient
2718.44,	410.029	4th layer - trapping layer
2892.62,	399.773	5th layer - subrefractive gradient
3500.0,	430.849	

EREPS binary file

Rather than using the EM propagation models internal to the EREPS programs to compute propagation loss, precomputed loss values may be read from a binary data file. There are several programs that can generate propagation loss versus height and range data as output. Their output could be formatted as described below, such that the loss data are readable by EREPS. One such program is NRaD's RPO program. See the on-line help associated with the PROP MODEL prompt on the INIT or GRAPH mode pages for more information about the RPO program.

The binary data file format consists of three parts.

◆ Part 1 consists of optional ASCII comments. EREPS 3.0 ignores all ASCII data up to the first end-of-file, *eof*, mark. The *eof* has an ASCII code of 26 and can be generated from a BASIC language by printing CHR$(26) to the file. The *eof* must be followed by a carriage return, *cr*, and line feed, *lf*, combination. The *cr* has an ASCII code of 13, the *lf* an ASCII code of 10, and they can be generated from BASIC by printing CHR$(13) and CHR$(10), respectively.

◆ Part 2, following the *eof cr lf* combination of the optional ASCII comments, consists of 14 lines of ASCII data containing the EREPS Version Label, file title, EM system, range, and height parameters. Each line of data is terminated by a *cr lf* combination. These 14 lines are:

Description	**ASCII character format**	
EREPS Version Label	EREPS 3.0 cr lf	
Title	up to 72 characters maximum cr lf	
Frequency (MHz)	real number cr lf	
Polarization	HORIZONTAL, VERTICAL, or CIRCULAR cr lf	
Antenna height (m)	real number cr lf	
Antenna type	OMNI, GAUSS, SINX/X, CSC-SQ, or HT-FIND cr lf	
Vertical beamwidth (deg)	real number cr lf	
Elevation angle (deg)	real number cr lf	
Number of heights	integer cr lf	note: must be ≥ 1
Minimum height (m)	real number cr lf	note: must be ≥ 1
Height increment (m)	real number cr lf	note: must be > 0
Number of ranges	integer cr lf	note: must be ≥ 1
Minimum range (m)	real number cr lf	note: must be > 0
Range increment (m)	real number cr lf	note: must be > 0

◆ Part 3 contains the binary data that follows the 14th *cr lf* combination of the ASCII data. The binary data consists of an array of propagation loss values in decibels times 10, rounded to the nearest integer. This maintains loss values to the nearest tenth of a decibel. The size of the array is equal to the number of height elements times the number of range elements times two bytes. The order for loss array values corresponds to

all heights, from minimum to maximum, at the minimum range, followed by all heights at the next range, etc. Each integer array value is written in MS-DOS format, i.e., two bytes long with the low byte first. When writing the loss data to a file in a BASIC language, each element is separated by a semicolon to suppress the carriage return line feed.

A sample Microsoft BASIC 7.1 program to create a binary file is:

```
OPEN filename$ FOR OUTPUT AS #1
FOR i = 1 TO NumComments              ' NumComments is number of
        PRINT #1, comment$(i)         'comment lines
NEXT
PRINT #1, CHR$(26)                    ' eof cr lf
PRINT #1, "EREPS 3.0"                 ' Version Number cr lf
PRINT #1, Frequency                   ' Frequency cr lf
'       ....                          ' similar statements for other
'       ....                          ' variables described above
'       ....
PRINT #1, RangeIncrement              ' Range Increment cr lf
FOR i = 1 TO NumRanges                ' Number of range increments
        FOR j = 1 TO NumHeights       ' Number of height increments
             n =CINT(PL(i,j) * 10)    ' PL(i,j) = Propagation Loss at the
             PRINT #1, MKI$(n);       ' ith range and jth height. Use ; to
        NEXT                          ' suppress cr lf
NEXT
CLOSE #1
END
```

The MKI$ function ensures the integer is written in the MS-DOS format.

Your own data file

You may plot your own data on EREPS axes to take advantage of the scaling and custom labeling features of EREPS, or you may want to overlay your own observed data upon an EREPS model output.

Selecting *Overlay* or *Plot* from the OPTIONS menu will open a file-handling window so you may specify the name of the file containing your data. The data conventions for the user data file are:

- **Key words and symbols** (key words are case insensitive)

- Any line that begins with a # is your comment and is ignored by the EREPS program.

@height - assignment of height units. Following this key word is another key word, either feet or ft; meters or m; kilofeet or kft; kilometers or km.

@range - assignment of range units. Following this key word is another key word, either kilometers or km; nautical miles or nmi; statute miles or sm; yards or yds; kiloyards or kyds.

- **Your data**

Your data must be arranged in two columns. Blank lines, spaces, data deliminators (i.e., a comma or spaces separating the two columns), and any characters following the second column are ignored. The use of @height and @range keywords depends upon your data. For example, if you want to overlay your data on a COVER or RAYS plot, both keywords are used. If you want to overlay your data on a PROPR plot, only @range is used.

- If no units key word(s) is(are) used, EREPS assumes:

Program	**First column**	**Second column**
PROPR	ranges in kilometers	values in dB
PROPH	heights in meters	values in dB
COVER	ranges in kilometers	heights in meters
RAYS	range in kilometers	heights in meters

The values in decibels may be path loss, propagation factor, or signal-to-noise ratio as defined by the PROPR or PROPH display option.

Climatology data file

When you select a Marsden square (or squares) from the SDS program's map, you may save the climatology in an ASCII file for your use in other programs. Since the climatological databases are now contained within the SDS program rather than in separate files as for EREPS 2.2, this option is the only way to access the data external to the SDS program. By simultaneously selecting every square (not the *WORLD AVERAGE* box), you may obtain the entire contents of the databases. The format and a sample of the file's contents for Marsden square 150 is:

```
System file for EREPS 3.0  Program SDS
MSQ150.SDS
6.60     # Average Evap Duct Ht (m)
9.00     # Average Wind speed (m/s). =  17.49 kts
2.00     # Surface based duct occurrence (%)
59.00    # Avg Surface based duct ht (m)
317.00 # Avg NSUBS
118.00 # Avg gradient.   Avg Rk= 1.330617
27.10    # % occurence  0 to 2 m
13.90    # % occurence  2 to 4 m
13.80    # % occurence  4 to 6 m
11.00    # % occurence  6 to 8 m
8.90     # % occurence  8 to 10 m
7.10     # % occurence  10 to 12 m

0.20     # % occurence  28 to 30 m
0.00     # % occurence  34 to 36 m
0.00     # % occurence  36 to 38 m
0.00     # % occurence  38 to 40 m
0.00     # % occurence  > 40 m
1        # Number of Masden squares tagged
1        # Number of RS Stations
#MSQ     Obs        Latitude     Longitude    Educt(m)  Wind(m/s)
150      170362#   40 to 50 N   50 to  60 W     6.6          9.0
#Rec  Lat   Lon   Obs  SBD Thick NsubS Mgrad MSQ  WMO    Name
162  47.30 54.00 982   2     59     317    118  150   72807 ARGENTIA, CANADA
```

EREPS Models

The various models underlying the EREPS programs are described below. PROPR, PROPH, COVER, RAYS, and FFACTR are all based on these models; however, for considerations of speed and graphics presentation, each program is implemented somewhat differently. The implementations for each model are briefly described at the end of this chapter. In the discussion of the models, heights are in meters, ranges are in kilometers, frequencies are in megahertz, losses and propagation factors are in decibels, and angles are in radians unless specifically stated otherwise.

Propagation Models

The simplest case of electromagnetic wave propagation is the transmission of a wave between a transmitter and a receiver in free space. Free space is defined as a region whose properties are isotropic, homogeneous, and loss-free, i.e., away from the influences of the earth's atmosphere. In free space, the electromagnetic wave front spreads uniformly in all directions from the transmitter.

While the total amount of energy transmitted does not vary, i.e., no losses to absorption, etc., the energy is distributed over an ever-enlarging surface. Thus the energy level along any one ray decreases inversely with the square of the sphere's radius. This is called the *free-space path loss*. The power density, P_a, over a sphere at any point in free space, is

$$P_a = \left(\frac{P_t}{4\pi r^2} \right) \quad (W/m^2) \tag{6}$$

where P_t is the power radiated by the transmitter and r is the radius of the sphere.

In free space, the power density at a loss-free, isotropic receiving antenna is the power density over the entire sphere's surface times the area of the sphere covered by the receiver antenna, also called the antenna's effective aperture, A_e. The effective aperture is related to the wavelength (λ) of radiation by

$$A_e = \frac{G\lambda^2}{4\pi} \tag{7}$$

where G is the antenna's gain. For a loss-free, isotropic antenna, G is unity. Thus the power at the receiver, P_r ,is

$$P_r = P_a A_e = \frac{P_t \lambda^2}{(4\pi r)^2} . \tag{8}$$

The free-space path loss expressed in terms of the sphere's radius, r, and wavelength, λ, where r and λ are in the same units is

$$L_{fs} = 10\log_{10}\left(\frac{P_t}{P_r}\right) = 10\log_{10}\left[\frac{(4\pi r)^2}{\lambda^2}\right] . \tag{9}$$

The free-space path loss expressed in terms of range, r, and frequency, f, is

$$L_{fs} = 32.44 + 20\log_{10}(r) + 20\log_{10}(f). \tag{10}$$

If nonisotropic antenna radiational patterns are considered within the loss calculations, the loss is referred to as *propagation loss* rather than path loss. The propagation loss can be described with the aid of the *propagation factor*, which is defined as the ratio of the actual field strength at a point in space to the field strength that would exist at the same range under free-space conditions, with the beam of the transmitter directed toward the point in question. Symbolically this is

$$F = \frac{|E|}{|E_o|} \tag{11}$$

where E_o is the magnitude of the electric field under free-space conditions, and E is the magnitude of the field to be investigated at the same point.

The propagation factor is a desirable quantity since it is an identifiable parameter in most radar-detection-range equations. It contains all the information necessary to account

for such effects as sea-surface reflection, atmospheric refraction, scattering from inhomogeneties in the atmosphere, and diffraction from the bulge of the earth's surface. Thus, if the functional form of F is known, then the propagation loss at any point can be determined since the calculation of the free-space field is quite simple. The propagation loss including antenna patterns, is equivalent to

$$L = L_{fs} - 20\log_{10}(F). \tag{12}$$

There are three distinct regions that require different methods for obtaining signal strength (or, equivalently, propagation loss) as a function of range. The first region is called the *optical interference*, or optical-region. This region extends roughly from the transmitter to the radio horizon. In the optical region, propagation is dominated by two-path coherent interference between direct and surface-reflected waves. The other distinct region is the *diffraction/troposcatter* region, which begins just beyond the radio horizon. A third region, called the *intermediate* region, lies between the optical and the diffraction region. The signal levels in this region are obtained by a linear interpolation between F values in the optical and diffraction regions.

Optical Interference Region

For EM systems operating near the earth's surface, the electric field at a receiving antenna or radar target is the vector sum of the field components that arrive at that point via the direct and sea-reflected paths. The phase component of the reflected ray will lag the phase of the direct path because of the difference in path lengths. The total phase lag, Θ, of the reflected ray with respect to the direct ray is the sum of the path-length difference, δ, and the phase change, Φ, due to reflection from the surface. In EREPS the assumption is made that the direct and sea-reflected rays have very nearly the same spatial direction, such that the major factor in their addition is the phase difference. Kerr (1951) gives the expression for F in the absence of abnormal absorption or refractive effects as

$$F = \sqrt{f(\varepsilon_1)^2 + f(\varepsilon_2)^2 + 2DRf(\varepsilon_1)^2 f(\varepsilon_2)^2 \mathrm{COS}(\Theta)}. \tag{13}$$

The $f(\varepsilon_i)$ factors describe the (normalized to 1) antenna pattern and the angles, ε_i, shown in figure 6-1. D is called the divergence factor and takes into account the spherical nature of the reflecting surface. R is the reflection coefficient of the reflecting surface (the ratio of the magnitudes of the reflected and incident fields). F varies from maximum to minimum as the total phase lag, Θ, changes by π, and can assume values between 0 and 2.

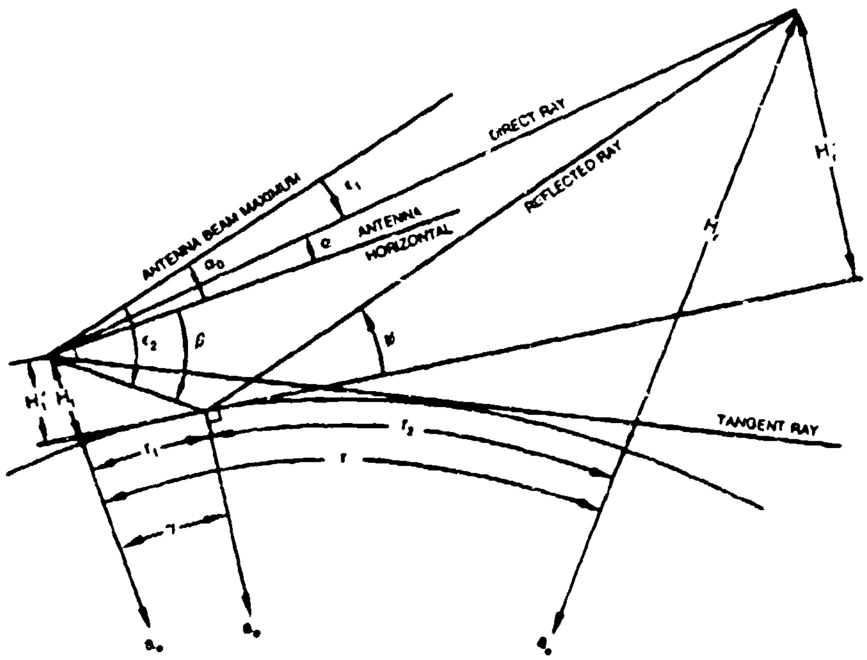


Figure 6-1: Two path optical interference region.

The expression for F in equation 13 is valid for all values of Θ such that the path-length difference, δ, is greater than or equal to $\frac{\pi}{2}$ (one-quarter wavelength), or at which the grazing angle is equal to a limit given by Reed and Russell (1966) at which the spherical earth divergence factor becomes invalid. This limit is given by the expression

$$\psi_{\lim} = \mathrm{TAN}^{-1}\left(\sqrt[3]{\frac{0.001\lambda}{2\pi a_e}}\right) \approx \frac{0.01957}{\sqrt[3]{kf}} \qquad (14)$$

where ψ is the grazing angle, λ is the wavelength, a_e is the effective earth radius, and f is the frequency. a_e is defined as the earth radius times the effective earth radius factor k.

The optical region maximum range is reduced from that calculated by the applicable optical region limit above if the evaporation duct is not zero. If the (scaled) evaporation duct height is less than 10.25 meters in height, the end of the optical region is obtained by finding the range where the first optical region peak occurs ($\Theta = 2\pi$) and using the formula

$$\Theta_{\lim} = 1 + \left(\frac{\Delta}{10.25}\right)(2\pi - \Theta_1), \tag{15}$$

where Θ_1 represents the value of Θ at the one-quarter wavelength or grazing angle limit, and Δ is the scaled evaporation duct height. Scaled evaporation duct heights greater than 10.25 meters use $\Theta = 2\pi$ as the optical region maximum value.

Optical Path Length Difference

For PROPR and PROPH, the path length difference, δ, in radians, between the direct and reflected rays is given by

$$\delta = 2\pi\left(\frac{2H_t' H_r'}{1000 r \lambda}\right). \tag{16}$$

Here r is the total ground range, and H_t' and H_r' the effective antenna heights. H_t' and H_r' are shown in figure 6-1 and are given by

$$H_t' = H_t - \frac{1000 r_1^2}{2a_e} \text{ and} \tag{17}$$

$$H_r' = H_r - \frac{1000 r_2^2}{2a_e} \tag{18}$$

where H_t and H_r are the transmitter and receiver/target heights, respectively, and r_1 and r_2 are the reflection point ranges. r_1 can be determined by solving the cubic equation

$$2r_1^3 - 3r\,r_1^2 + \left(r^2 - 0.002\,a_e\left(H_t + H_r\right)\right)r_1 + 0.002a_e\,H_t\,r = 0. \tag{19}$$

This equation is frequently solved using a Newton-method iterative technique, but also has the formal solution (for $H_r \geq H_t$)

$$r_1 = \frac{r}{2} - p\,\mathrm{COS}\left(\frac{\Phi + \pi}{3}\right) \quad \text{where} \tag{20}$$

$$p = \sqrt{\frac{4}{3}\left(0.001\,a_e\left(H_t + H_r\right) + \frac{r^2}{4}\right)} \quad \text{and} \tag{21}$$

$$\Phi = \mathrm{COS}^{-1}\left(\frac{0.002\,a_e\left(H_r - H_t\right)r}{p^3}\right). \tag{22}$$

The antenna pattern factors, $f(\varepsilon_i)$, require angular information about the angles α and β as shown in figure 6-1. The magnitude, R, and phase shift, Φ, require knowledge of the grazing angle, ψ. These angles are

$$\alpha = \frac{0.001\left(H_r - H_t\right)}{r} - \frac{r}{2a_e}, \tag{23}$$

$$\psi = 0.001\left(\frac{H_t'}{r_1}\right), \tag{24}$$

$$\gamma = \frac{r_1}{a_e}, \text{ and} \tag{25}$$

$$\beta = -\gamma - \psi \tag{26}$$

in terms of quantities shown in figure 6-1. The divergence factor is calculated using the equation

$$D = \frac{1}{\sqrt{\frac{1 + 2 r_1 r_2}{r a_e \psi}}} . \tag{27}$$

For the COVER program only, the path-length difference is based on the assumption that the direct and reflected rays are parallel. The path-length difference for this model is given by Blake (1970) as

$$\delta = \frac{4\pi}{\lambda} \mathrm{SIN}^2(\psi) \sqrt{H_t^2 + 1000 a_e (1000 a_e + H_t) \gamma^2} \tag{28}$$

where

$$\gamma = \sqrt{\frac{\mathrm{TAN}^2(\alpha)}{9} + \frac{2000 H_t}{3 a_e}} - \frac{\mathrm{TAN}(\alpha)}{3} . \tag{29}$$

The grazing angle for the COVER program is calculated using

$$\psi = \alpha + \gamma , \tag{30}$$

and β, the launch angle of the reflected ray, is equal to

$$\beta = -\alpha - 2\gamma . \tag{31}$$

The divergence factor, in terms of the quantities of equations 29 and 30, is

$$D = \frac{1}{\sqrt{1 + \frac{2\gamma}{\mathrm{SIN}(\psi)}}} . \tag{32}$$

The parallel ray assumption simplifies the determination of the COVER contours since each contour is described by

$$r = R_{fs} F \,\mathrm{COS}(\alpha) \tag{33}$$

for all angles α within the main beam of the antenna and greater than the lower angular limit of the optical region. Here R_{fs} is the free-space range.

Reflection Coefficients

The magnitude, R, and phase shift, Φ, of the reflected ray can be calculated as a function of the grazing angle ψ. For horizontal and vertical polarizations, these are

$$R_H = 1, \tag{34}$$

$$\Phi = \pi \text{, and} \tag{35}$$

$$R_V^{i\Phi_V} = \frac{n^2 \mathrm{SIN}(\psi) - \sqrt{n^2 - \mathrm{COS}^2(\psi)}}{n^2 \mathrm{SIN}(\psi) + \sqrt{n^2 - \mathrm{COS}^2(\psi)}} \tag{36}$$

where n is the (complex) index of refraction and the subscripts H and V indicate the polarization. The reflection coefficient for circular polarization is calculated in terms of the horizontal and vertical coefficients as

$$R_C = 0.5\sqrt{R_V^2 + R_H^2 + 2R_V\ R_H \mathrm{COS}(\Phi_H - \Phi_V)} \quad \text{and} \tag{37}$$

$$\Phi_C = \Phi_H - \mathrm{SIN}^{-1}\left[\frac{R_V\ \mathrm{SIN}(\Phi_H + \Phi_V)}{2R_C}\right] \tag{38}$$

The magnitude of the reflected ray is also affected by the roughness of the reflecting surface. Surface roughness is included using the International Radio Consultative Committee (CCIR) (1990) model. The CCIR model is an approximation to the modified Bessel functions derived by Miller, Brown, and Vegh (1984), which agree with the values measured by Beard (1961). The model formulation is

$$R = \frac{R_o}{\sqrt{3.2x - 2 + \sqrt{(3.2x)^2 - 7x + 9}}} \quad \text{where} \tag{39}$$

$$x = 0.5g^2 \text{ and} \tag{40}$$

$$g = \frac{4\pi \hbar \mathrm{SIN}(\psi)}{\lambda}. \tag{41}$$

Here R_o is the reflection coefficient for a smooth surface, $\hbar$ is the root-mean-squared wave height, and λ the wavelength. The rms wave height is obtained as a function of wind speed using the Phillips (1966) ocean-wave model

$$\hbar = 0.0051\, W_s^2 \tag{42}$$

for wind speed, W_s, in meters per second.

The square of the index of refraction required to make the calculation of R and Φ for vertical and circular polarizations is given by

$$n^2 = \varepsilon - \frac{i(18000\sigma)}{f} \tag{43}$$

where ε and σ are the ordinary dielectric constant and conductivity, respectively, of seawater, and f is the EM system frequency. The constants themselves are obtained as a function of frequency using polynomial functions that were curve-fit to the CCIR (1990) curves for seawater of average salinity at 20° C. The dielectric constant, or relative permittivity, ε, is

$$\varepsilon = 70 \qquad \text{for } f \leq 2253.5895 \text{ and} \tag{44}$$

$$\varepsilon = \frac{1}{a + bf + cf^2 + df^3 + ef^4} \qquad \text{for } f > 2253.5895 \tag{45}$$

where:

$a = 1.4114535 \cdot 10^{-2}$,

$b = -5.2122497 \cdot 10^{-8}$,

$c = 5.8547829 \cdot 10^{-11}$,

$d = -7.6717423 \cdot 10^{-16}$, and

$e = 2.9856318 \cdot 10^{-21}$.

The surface conductivity, σ, is

$$\sigma = 5.0 \qquad \text{for } f \le 1106.207 \text{ and} \tag{46}$$

$$\sigma = \frac{r + t\,f + v\,f^2}{1 + s\,f + u\,f^2 + w\,f^3} \qquad \text{for } f > 1106.207 \tag{47}$$

where:

$$\begin{aligned} r &= 3.8586749, \\ s &= -2.1179295 \cdot 10^{-5}, \\ t &= 9.1253873 \cdot 10^{-4}, \\ u &= 6.5727504 \cdot 10^{-10}, \\ v &= 1.5309921 \cdot 10^{-8}, \text{ and} \\ w &= -1.9647664 \cdot 10^{-15}. \end{aligned}$$

These polynomial functions fit the CCIR curves to within ± 5 percent in the 100-MHz to 100-GHz frequency range.

Antenna Pattern Factors

The remaining terms in equation 13, $f(\varepsilon_i)$, the normalized antenna pattern factors, are determined as a function of the antenna pattern type, beamwidth, and pointing angle. Five different antenna types are used in EREPS: omnidirectional, sin(x)/x, cosecant-squared, generic height-finder, and Gaussian beam. The first and simplest case is that of the omnidirectional antenna which, as its name implies, has a gain of unity in all directions. That is, $f(\mu) = 1$ for all angles μ.

The second case is the sin(x)/x antenna type. The radiation pattern of this antenna is symmetric about the elevation (pointing) angle of the antenna. The pattern factor for this antenna is given by Blake (1970) as

$$f(\mu) = \frac{\mathrm{SIN}(x)}{x} \geq 0.03 \qquad \text{for } -\mu_{\max} \leq \mu \leq \mu_{\max}, \tag{48}$$

where

$$x = c\,\mathrm{SIN}(\mu - \mu_o). \tag{49}$$

μ_o and $\mu_{\max}$ are the elevation angle and maximum angle in the main beam, respectively. The value of c is chosen so that $f(\mu) = 0.7071$ when $\mu = \mu_o \pm \frac{\mathrm{BW}}{2}$, where BW is the beamwidth. This normalization ensures that the antenna half-power points $[20\mathrm{LOG}_{10}(f(\mu)) = -3\,\mathrm{dB}]$ occur at $\mu = \mu_o \pm \frac{\mathrm{BW}}{2}$, which is the usual definition of the beamwidth of the antenna. That is

$$c = \frac{1.39157}{\mathrm{SIN}\left(\frac{\mathrm{BW}}{2}\right)}. \tag{50}$$

Pattern factor calculations are limited to those angles within the main beam of the antenna down to the -30 dB level ($f(\mu) \geq 0.03$). Angles greater than

$$\mu_{\max} = \mu_o \pm \mathrm{TAN}^{-1}\left(\frac{A}{\sqrt{1 - A^2}}\right) \tag{51}$$

where $A = \frac{\pi}{x}$, are limited to a pattern factor of 0.03. This is equivalent to an antenna with its first sidelobes at -30 dB, a condition easily achieved with modern antennas.

The generic height-finder antenna is a special case of the sin(x)/x antenna. Height-finder antennas typically sweep the beam upward in elevation. This can be simulated by substituting the direct ray angle, μ, for the elevation angle μ_o. Then $f(\mu) = 1$ for all values, μ, of the direct ray set. As the antenna beam is swept upward, the pattern factor for the reflected ray gradually tapers to the -30 dB level.

A fourth antenna type is the cosecant-squared antenna. This antenna pattern is not symmetric about the elevation angle. The pattern factor is calculated using

$$f(\mu)=1 \qquad \text{for } \mu_o \le \mu \le (\mu_o+\mathrm{BW}), \tag{52}$$

$$f(\mu)=\frac{\mathrm{SIN(BW)}}{\mathrm{SIN}(\mu-\mu_o)} \qquad \text{for } \mu > (\mu_o+\mathrm{BW}), \text{ and} \tag{53}$$

$$f(\mu)=\left[1-\frac{\mu-\mu_o}{\mathrm{BW}}\right]\ge 0.03 \qquad \text{for } \mu<\mu_o. \tag{54}$$

This antenna pattern is different from the sin(x)/x or Gaussian beam antennas since the beamwidth of this antenna does not coincide with the -3 dB, or half-power, points of the antenna. The orientation of the antenna given above is the one that would be used for shipboard radars. Cosecant-squared antennas used on an airborne radar are normally oriented in the reverse sense such that equations 52 and 53 describe the direct ray angles below the elevation angle μ_o. Equation 54 then describes the beam taper above the elevation angle. The antenna orientation is not optional in EREPS; the antenna is always assumed to be that of a surface-based system.

The final antenna option is the Gaussian beam antenna. The pattern factor for this antenna is symmetric about the pointing angle and is given by

$$f(\mu)=e^{\frac{-W^2(P-P_o)^2}{4}}\ge 0.0 \qquad \text{for } -\mu_{\max}\le\mu\le\mu_{\max}, \tag{55}$$

and where

$$P=\mathrm{SIN}(\mu), \tag{56}$$

$$P_o=\mathrm{SIN}(\mu_o), \tag{57}$$

$$W=\frac{\sqrt{2\,\mathrm{LOG}_e(2)}}{\mathrm{SIN}\left(\frac{\mathrm{BW}}{2}\right)}. \tag{58}$$

W, the normalization factor, is chosen such that $f(\mu)=0.7071$ when $\mu=\mu_o \pm \frac{\text{BW}}{2}$, similar to the sin(x)/x antenna. The maximum angle is calculated using equation 51, with A defined as

$$A=\sqrt{10.11779\ \text{SIN}^2\left(\frac{\text{BW}}{2}\right)}. \tag{59}$$

Diffraction/Intermediate Region Models

Beyond the horizon, the chief contributions to the electric field are from diffraction and, at somewhat greater ranges, tropospheric scatter. The diffraction field can be represented as a sum over the possible number of modes, which is the solution to the fundamental equation of mode theory. For a standard atmosphere, the series describing the field converges rapidly and only a single mode is necessary to adequately determine the field. A single mode may also describe the field in the presence of evaporation ducts or surface-based ducts due to elevated layers, especially the former. However, close to the horizon the series solution converges rather slowly. This is the intermediate region, and a method of *bold interpolation* originally described by Kerr (1951) is used to estimate the field in this region. This method involves a linear interpolation on the logarithm of the pattern propagation factor from the last valid range in the optical region to the first range in the diffraction region.

The minimum range at which the diffraction field solutions are applicable and the intermediate region ends is given by Reed and Russell (1966) as

$$r_d = r_{hor} + 230.2\sqrt[3]{\frac{k^2}{f}}. \tag{60}$$

where k is the effective earth radius and f is EM system frequency. For the transmitter and receiver heights, H_t and H_r respectively, the horizon range is given by

$$r_{hor} = 3.572\left(\sqrt{k H_t}+\sqrt{k H_r}\right). \tag{61}$$

A minimum effective earth radius of 1.33 is assumed for the calculation of r_d.

The diffraction/intermediate region models are used to determine propagation loss as a function of height and range for ranges and heights below the lower angular limit of the optical interference region. There are four models used to calculate loss in this region. If the evaporation duct height is zero, then the standard diffraction loss is calculated by the methods outlined by the CCIR (1990). If the evaporation duct height is not zero, then the least loss from standard diffraction or a model derived from the NRaD waveguide program is used. If a surface-based duct is present, an empirical model is used to calculate loss. At somewhat greater ranges, troposcatter loss is calculated using a model taken from Yeh (1960) that has been modified by the addition of a *frequency gain* factor from Rice, et al. (1965) that gives better values for low-altitude paths. The troposcatter loss is calculated for all range-height combinations beyond r_d and added to the standard diffraction or evaporation duct loss until the troposcatter loss is 18 dB less than the applicable loss. Beyond that point, only the troposcatter loss is calculated.

Standard Diffraction Model

The total propagation loss due to standard diffraction (from equation 12) is given by

$$L = L_{fs} - 20\text{LOG}_{10}(F) - L_d \qquad (62)$$

in terms of previously defined quantities. The diffraction field antenna pattern loss term, L_d, is determined using

$$L_d = 20\text{LOG}_{10}(f(\mu)), \qquad (63)$$

where the antenna pattern factor, $f(\mu)$, gives a measure of how much energy is directed toward this region, and μ represents the lowest direct ray angle in the optical region. The CCIR (1990) standard diffraction model specifies the one-mode solution for F as

$$20\text{LOG}_{10}(F) = V(X) + G(Z_1) + G(Z_2) \qquad (64)$$

for a standard atmosphere. X, Z_1, and Z_2 are the receiver/target range, transmitting antenna height and receiver/target height, respectively, expressed as unitless quantities. X and Z_i are given by

$$X = \frac{2.2\beta r \sqrt[3]{f}}{\sqrt[3]{a_e^2}} \quad \text{and} \tag{65}$$

$$Z_i = \frac{0.0096\beta H_i \sqrt[3]{f^2}}{\sqrt[3]{a_e}} . \tag{66}$$

The subscript i refers to either the transmitter or radar target/receiver height. β is a parameter that accounts for surface characteristics and EM polarization effects. $\beta = 1$ for horizontal polarization and is calculated for vertical or circular polarizations as

$$\beta = \frac{1+1.6K^2+0.75K^4}{1+4.5K^2+1.35K^4} \quad \text{for } f < 300 \text{ MHz}. \tag{67}$$

K is a function of polarization and is given by

$$K_H = \frac{0.36}{\sqrt[3]{a_e f}\ \sqrt[4]{(\varepsilon-1)^2+\left(\frac{18000\sigma}{f}\right)^2}} \tag{68}$$

and

$$K_C = K_V = K_H \sqrt{\varepsilon^2+\left(\frac{18000\sigma}{f}\right)^2} . \tag{69}$$

ε and σ are the relative permittivity and conductivity obtained from equations 44 through 47 and the subscripts H, V, and C refer to horizontal, vertical, and circular polarizations.

The V(X) term of equation 64 represents the signal attenuation with range and is equal to

$$V(X) = 11 + 10\text{LOG}_{10}(X) - 17.6X \quad \text{(dB)}. \tag{70}$$

The height-gain functions, $G(Z_i)$, of equation 64 are calculated, in decibels, as follows

$$G(Z_i)=17.6\sqrt{Z_i-1.1} - 5\mathrm{LOG}_{10}(Z_i-1.1)-8 \qquad \text{for } Z_i > 2, \tag{71}$$

$$G(Z_i)= 20\mathrm{LOG}_{10}\left(Z_i+0.1Z_i^3\right) \qquad \text{for } 10K < Z_i \le 2, \tag{72}$$

$$G(Z_i)=2+20\mathrm{LOG}_{10}(K)+9\mathrm{LOG}_{10}\left(\frac{Z_i}{K}\right)\left[\mathrm{LOG}_{10}\left(\frac{Z_i}{K}\right)+1\right] \tag{73}$$

for $\frac{K}{10} < Z_i \le 10K$, and

$$G(Z_i)= 2+20\mathrm{LOG}_{10}(K) \qquad \text{for } Z_i \le \frac{K}{10.0}. \tag{74}$$

NRaD Evaporation Duct Model

The evaporation duct loss (in dB) may be written as

$$L=51.1+\Gamma-F_{zt}-F_{zr}+10\mathrm{LOG}_{10}(\rho)+\alpha\rho-L_a \tag{75}$$

L_d is defined by equation 63. Γ is the excitation factor, F_{zt} and F_{zr} the height-gain functions for the EM system transmitter and radar target/receiver, respectively, ρ the (scaled) range, and α the attenuation rate. The specific values of these quantities are obtained as functions of the duct height. The functions that produce these values are the result of curve-fitting the various quantities to waveguide program solutions. F is obtained by substituting equation 75 into equation 12.

The waveguide solutions that were used to develop the evaporation duct model were made at a single frequency, 9600 MHz. The evaporation duct solutions for other frequencies share a family resemblance, the height of the duct, which produces a particular propagation characteristic varying inversely with the frequency. This fact allows the solutions at 9600 MHz to be scaled to other frequencies. To perform the scaling, all actual ranges and heights are multiplied by the scale factors

$$R_N = \sqrt[3]{\frac{f}{9600}} \quad \text{and} \tag{76}$$

$$Z_N = \sqrt[3]{\left(\frac{f}{9600}\right)^2} \text{, respectively.} \tag{77}$$

These factors ensure $R_N = Z_N = 1.0$ when the frequency equals 9600 MHz. For example, the scaled duct height, Δ, is equal to the product of the actual evaporation duct height, δ and Z_N; the scaled range, ρ, is the product of the actual range, r and R_N; and the scaled transmitter height, z_t, is the product of the actual transmitter height, H_t, and Z_N.

The height-gains expressed as a function of scaled duct height are of two different forms, depending on whether or not the duct height is sufficient to support a well-trapped mode. The height gain function (in decibels) for scaled duct heights less than 10.25 meters may be written as

$$F(z) = C_1 z^{C_2} + C_3 z^{C_4} + C_5 \qquad \text{for } z \geq 1.0, \tag{78}$$

where z is the scaled height of either the EM system transmitter or the radar target/receiver. The coefficients are

$$C_1 = \left(-2.2e^{-0.244\Delta} + 17\right) 4.72^{-C_2}, \tag{79}$$

$$C_2 = \sqrt{40623.61 - (\Delta + 4.4961)^2} - 201.0128, \tag{80}$$

$$C_3 = \left(-33.9e^{-0.517\Delta} - 3\right) 4.72^{-C_4}, \tag{81}$$

$$C_4 = \sqrt{143012 - (\Delta + 5.32545)^2} - 119.569, \text{ and} \tag{82}$$

$$C_5 = 41e^{-0.41\Delta} + 61. \tag{83}$$

For well-trapped modes, (scaled duct heights between 10.25 and 23.3 meters), two functions are necessary to obtain the height-gains in decibels,

$$F(z)=C_1\ \mathrm{LOG}_e\left[\mathrm{SIN}\left(C_2\, z^{C_3}\right)\right]+C_4 \qquad \text{for } 1.0 \le z \le z_{max} \text{ and} \tag{84}$$

$$F(z)= C_5\, z^{C_6} + C_7 \qquad \text{for } z > z_{max}. \tag{85}$$

z_{max} is calculated using the formula

$$z_{max} = 4\, e^{(-0.31[\Delta - 10])} + 6\ , \tag{86}$$

and the coefficients are

$$C_1 = -0.1189\Delta + 5.5495, \tag{87}$$

$$C_2 = \left[1.3291\,\mathrm{SIN}\left(0.218(\Delta - 10)^{0.77}\right) + 0.2171\,\mathrm{LOG}_e(\Delta)\right]4.72^{-C_3}, \tag{88}$$

$$C_3 = 1.5, \tag{89}$$

$$C_4 = 87 - \sqrt{313.29 - (\Delta - 25.3)^2}, \tag{90}$$

$$C_5 = \frac{F_{max}}{(z_{max})^{C_6}}, \tag{91}$$

$$C_6 = \left(\frac{z_{max}}{4.72}\right)\left(\frac{S}{F_{max}}\right), \text{ and} \tag{92}$$

$$C_7 = 49.4\, e^{-0.1699(\Delta - 10)} + 30 \tag{93}$$

where

$$S = \frac{4.72\, C_1\, C_2\, C_3 \sqrt{z_{max}}}{\mathrm{TAN}\left(C_2\,(z_{max})^{C_3}\right)} \quad \text{and} \tag{94}$$

$$F_{\max} = C_1 \ \mathrm{LOG}_e\left[\mathrm{SIN}\left(C_2 \left(z_{\max}\right)^{C_3}\right)\right] + C_4 - C_7 \ . \qquad (95)$$

which are necessary to make the two functions $F(z)$ and their slopes continuous about $z_{\max}$.

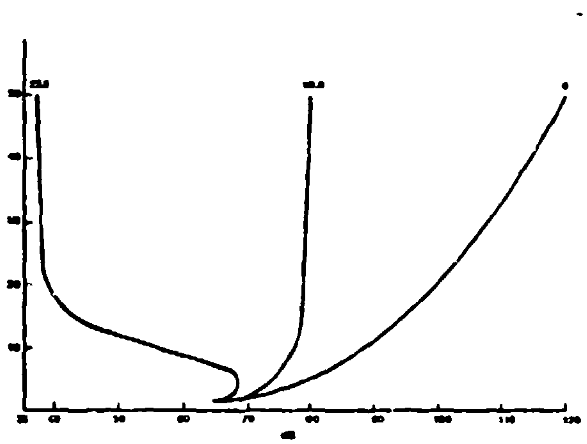


Figure 6-2: Evaporation Duct Height-Gain Curves.

Using these coefficients in the equations will produce height-gain curves (as shown for three duct heights of 0, 10, and 23.3 meters), which increase with height for scaled duct heights below 10.25 meters. The well-trapped modes have an initial increase with height for a limited range of z near the surface, peak, and then decrease with height to some value, thereafter displaying very little variation with height. The minimum scaled height used for calculating the height-gains is 1.0 meter, and heights below this are set equal to this value.

Scaled duct heights greater than 23.3 meters have more than one mode that propagates in the guide. The effect of these multiple modes is to add constructively at some range/height combinations and destructively at others, a condition similar to the optical region interference. Since this variation is not predictable without using a waveguide program, scaled duct heights greater than 23.3 meters are treated as 23.3-meter ducts.

Two factors from equation 75 remain to be specified: Γ and α. The excitation factor, Γ, which is a measure of the relative strength of the mode, is obtained by

$$\Gamma = 216.7 + 1.5526\Delta \qquad \text{for } \Delta \leq 3.8 \text{ and} \qquad (96)$$

$$\Gamma = 222.6 - 1.1771(\Delta - 3.8) \qquad \text{for } \Delta > 3.8 . \qquad (97)$$

The attenuation rate, α, in decibels per kilometer is

$$\alpha = 92.516 - \sqrt{8608.7593 - (\Delta - 20.2663)^2} \qquad (98)$$

for values of $\alpha \geq 0.0009$, which is the lowest attenuation rate used. It is convenient to replace the attenuation rate term in equation 75, $\alpha\rho$, with βr, where r is the actual range and

$$\beta = \alpha R_N . \tag{99}$$

The attenuation rates for the higher duct heights may be several orders of magnitude smaller than the standard diffraction (zero-meter duct height) rate.

NRaD Surface-Based Duct Model

The NRaD model for a surface-based duct from elevated layer is based on an empirical fit to experimental data. The loss is

$$L = 32.44 + 20\mathrm{LOG}_{10}(f) - F_{zr} + 20\mathrm{LOG}_{10}(r) - L_d , \tag{100}$$

where F_{zr} is the height-gain function for the receiver/target height, L_d is defined in equation 63, and f is the EM system's frequency. The attenuation rate term is not used in this model nor are range or height scale factors. As duct thicknesses are normally on the order of hundreds of meters, these ducts affect frequencies as low as 100 MHz, unlike the evaporation duct, which only affects frequencies greater than 1 GHz. This model has the disadvantage of being anisotropic with choice of terminal heights. F is obtained by substituting equation 100 into equation 12.

The height-gain function is calculated as a function of frequency and duct height, D, for any arbitrary radar target/receiver height z:

Case 1: $100 \leq f < 150$

$$F_{zr} = -60\left[\left(\frac{z}{D}\right) - 0.5\right]^2 \qquad \text{for } \frac{z}{D} < 0.8 \text{ and} \tag{101}$$

$$F_{zr} = 1.14\left(\frac{z}{D}\right)^{-6.26} - 10 \qquad \text{for } \frac{z}{D} \geq 0.8 . \tag{102}$$

Case 2: $150 < f \leq 350$

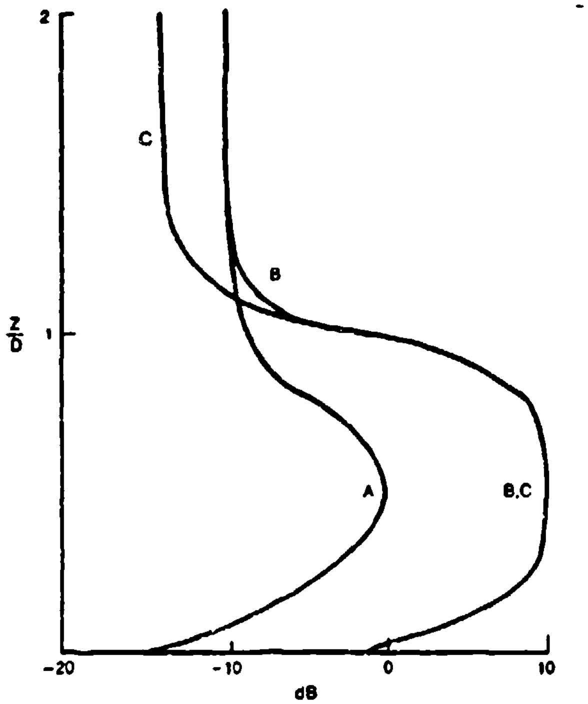
$$F_{zr} = 10 - 200\left[\left(\frac{z}{D}\right) - 0.5\right]^4 \qquad \text{for } \frac{z}{D} < 1.0 \text{ and} \qquad (103)$$

$$F_{zr} = 7.5\left(\frac{z}{D}\right)^{-13.3} - 10 \qquad \text{for } \frac{z}{D} \geq 1.0. \qquad (104)$$

Case 3: $f > 350$

$$F_{zr} = 10 - 200\left[\left(\frac{z}{D}\right) - 0.5\right]^4 \qquad \text{for } \frac{z}{D} < 1.0 \text{ and} \qquad (105)$$

$$F_{zr} = 12.5\left(\frac{z}{D}\right)^{-8} - 15 \qquad \text{for } \frac{z}{D} \geq 1.0. \qquad (106)$$



Examples of the height-gain curves produced by these formulas are shown by the curves labeled "A" ($100 \leq f < 150$), "B" ($150 \leq f < 350$), and "C" ($f \geq 350$). The shapes of the height-gain curves are characteristic of well-trapped modes as one would expect from a surface-based duct.

Figure 6-3: Surface-based Duct Height-Gain Curves.

The surface-based duct model assumes the upper 10 percent of the surface-based duct is the trapping layer. Below the trapping layer, the refractivity gradient is set equal to

the inverse of the effective earth radius ($dM/dh = 0.001 a_e^{-1}$). The gradient within the trapping layer is calculated from the assumption that the M-unit value at the top of the duct is equal to the M-unit value at the surface. If both the transmitter and the radar target/receiver height are below the trapping layer, a *skip zone* is modeled.

The skip zone range is determined with a raytrace using a ray launch angle of

$$\alpha = 10^{-3}\sqrt{2(M_{Ht} - M_{\min})} - 10^{-6}. \tag{107}$$

Here M_{Ht} is the M-unit value at the transmitter and $M_{\min}$ is the M-unit value at the surface-based duct height. The ray path between the two terminal heights is calculated using the raytrace equations, and the resulting range, r_{skip}, is the minimum range at which full trapping by the duct exists (i.e., the far end of the skip zone). For $r \geq r_{skip}$, the loss is given by equation 100. At lesser ranges, an additional loss of 1 dB/km for all frequencies, based on measured data, is added to the loss given by equation 100.

Troposcatter Region Model

At ranges sufficiently greater than the horizon, scattering from irregularities in the troposphere begins to dominate the electric field. Yeh (1960) gives the troposcatter loss as

$$\begin{aligned} L = 114.9 + \frac{0.08984(r - r_{hor})}{k} + 20\mathrm{LOG}_{10}(r) \\ + 30\mathrm{LOG}_{10}(f) - 0.2N_s - L_d + H_0. \end{aligned} \tag{108}$$

Here r is the range, r_{hor} is the horizon range, N_s is the surface refractivity value, and H_0 is the frequency-gain function from Rice et al. (1965). L_d is defined in equation 63. F is obtained by substituting equation 108 into equation 12.

You may suppress the troposcatter model by setting $N_s = 0$ if you want to compare EREPS with another model that does not account for troposcatter.

The frequency gain function, H_0, is primarily of importance for low antenna heights, especially if the system frequency is very low. The procedure for obtaining H_0 requires a calculation of the effective scattering height, h_0, which is equal to

$$h_0 = \frac{sr\Theta}{(1+s)^2} \quad (\text{km}), \tag{109}$$

where r is the ground range, Θ the scattering angle, and s is defined by

$$s = \frac{\varsigma}{\chi} \quad \text{for } 0.10 \le s \le 10.0. \tag{110}$$

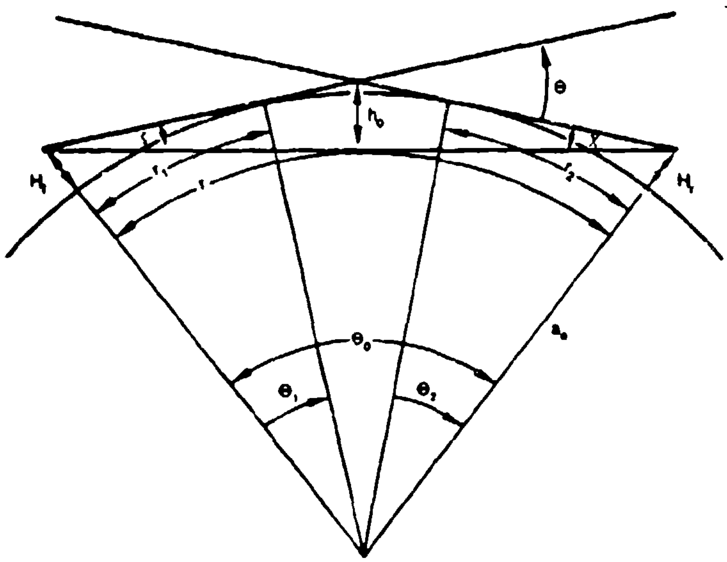


Figure 6-4: Various Angle Illustrations.

The illustrated angles from these equations are given by

$$\Theta = \Theta_0 - \Theta_1 - \Theta_2, \tag{111}$$

$$\Theta_0 = \frac{r}{a_e}, \tag{112}$$

$$\Theta_1 = \frac{r_1}{a_e}, \tag{113}$$

$$\Theta_2 = \frac{r_2}{a_e}, \tag{114}$$

$$\varsigma = \frac{\Theta_0}{2} - \Theta_1 + \frac{0.001(H_t - H_r)}{r}, \text{ and} \tag{115}$$

$$\chi = \frac{\Theta_0}{2} - \Theta_2 + \frac{0.001(H_r - H_t)}{r}, \tag{116}$$

defined in terms of the effective earth radius, a_e, the tangent ray ranges r_1 and r_2, terminal heights H_t and H_r, and the total range, r. The tangent ranges are equal to

$$r_1 = \sqrt{0.002\, a_e H_t} \quad \text{and} \tag{117}$$

$$r_2 = \sqrt{0.002\, a_e H_r}. \tag{118}$$

The frequency gain function is then defined as

$$H_0 = H_1 + \Delta H_0 = \frac{H_0(R_1) + H_0(R_2)}{2} + \Delta H_0 \quad \text{(dB)} . \tag{119}$$

If ΔH_0 is greater than H_1, then H_0 is equal to twice the value of H_1. The function H_1 is calculated using

$$H_0(R_1) = c_1 \sqrt[3]{\frac{1}{(R_1 + c_2)^4}} \quad \text{and} \tag{120}$$

$$H_0(R_2) = c_1 \sqrt[3]{\frac{1}{(R_2 + c_2)^4}} , \tag{121}$$

where R_1 and R_2 are functions of the terminal heights and EM system frequency, f,

$$R_1 = 0.0419 f H_t \Theta \qquad \text{for } R_1 \geq 0.1 \text{ and} \tag{122}$$

$$R_2 = 0.0419 f H_r \Theta \qquad \text{for } R_2 \geq 0.1 , \tag{123}$$

and the terms c_1 and c_2 are defined as

$$c_1 = 16.3 + 13.3 \eta_s \text{ and} \tag{124}$$

$$c_2 = 0.40 + 0.16 \eta_s . \tag{125}$$

The factor, η_s, where $0.01 \leq \eta_s \leq 5.0$, is a function of h_0 given by

$$\eta_s = 0.5696 h_0 \left[1 + \left(0.031 - 0.00232 N_s + 5.67 \cdot 10^{-6} N_s^2 \right) e^{-3.8 \cdot 10^{-6} h_0^6} \right] \tag{126}$$

The correction term, ΔH_0, in decibels, is

$$\Delta H_0 = 6 \left[0.6 - \mathrm{LOG}_{10}(\eta_s) \right] \mathrm{LOG}_{10}(s) \mathrm{LOG}_{10}(q) , \tag{127}$$

where q is given by

$$q = \frac{R_2}{s R_1} \qquad \text{for } 0.1 \le q \le 10.0 . \tag{128}$$

ΔH_0 is zero when $\eta_s = 4.0$, $s = 1.0$, or $q = 1.0$ and has a maximum value of 3.6 for highly asymmetrical paths when $\eta_s = 1.0$.

Water Vapor Absorption Model

The loss attributable to water vapor absorption is added to all other losses. The model is taken directly from CCIR recommendations (1990) and is dependent on the absolute humidity in grams/cubic meter. A temperature of 15° C is assumed. The water vapor absorption loss is equal to

$$L_{wv} = r \, \alpha_{wv} \tag{129}$$

where α_{wv} is the water vapor attenuation rate. The water vapor attenuation rate in dB/km is

$$\alpha_{wv} = \left[0.05 + 0.0021 H_a + \alpha_{wv1} + \alpha_{wv2} + \alpha_{wv3}\right] f^2 H_a 10^{-10} \tag{130}$$

where H_a is the absolute humidity, f is the EM system frequency, and

$$\alpha_{wv1} = \frac{3.6}{(0.001 f - 22.2)^2 + 8.5}, \tag{131}$$

$$\alpha_{wv2} = \frac{10.6}{(0.001 f - 183.3)^2 + 9}, \quad \text{and} \tag{132}$$

$$\alpha_{wv3} = \frac{8.9}{(0.001 f - 325.4)^2 + 26.3}. \tag{133}$$

For frequencies below about 10,000 MHz, this attenuation is negligible, but at the highest frequencies used in EREPS (20,000 MHz) the contribution can be quite noticeable, in particular at long ranges. No model is included for oxygen absorption.

Sea Clutter Models

Sea-surface clutter is shown for PROPR or PROPH display option 4. The sea clutter level is displayed by superimposing a plot of the ratio of clutter-to-noise power upon the propagation loss curve. The clutter may be the average clutter power or the average clutter power ±5 dB, i.e., the clutter power bounds. The clutter-to-noise ratio in decibels is equivalent to P_c - P_n, where P_c is the clutter power and P_n is the noise power in decibels. The average clutter power is

$$P_c = -123 + 10\mathrm{LOG}_{10}\left(P_t \lambda^2 r^{-4} f(\alpha)^4\right) + 2G_t + \sigma_c - L_s \,. \tag{134}$$

where P_t is the transmitted power in kiloWatts, λ is the wavelength in meters, r the range in kilometers, L_s is miscellaneous system losses in decibels, and σ_c is the average clutter cross-section in decibels. G_t is the antenna gain in decibels and $f(\alpha)$ is the antenna pattern factor associated with the ray launch angle, α, that intercepts the sea surface.

The noise power is

$$P_n = 10\mathrm{LOG}_{10}\left(\frac{4}{\tau\, 10^{15}}\right) + N_f \tag{135}$$

where N_f is the receiver noise figure in decibels and τ is the pulse width in microseconds. In PROPR this clutter-to-noise ratio is a function of range but for PROPH it is a constant.

Sea-surface clutter effects are included in EREPS using a NRaD-modified version of the Georgia Institute of Technology (GIT) model (Horst, 1978). These models differ below 1 degree grazing angle for low sea states and ducting conditions. The GIT model is thought to be valid to ±5 dB. The NRaD modifications allow the clutter calculations to

be extended beyond the normal horizon under evaporation ducting conditions. The NRaD model provides greater reflectivity than the GIT model for low grazing angle/evaporation ducting conditions. The sometimes dramatic effects of surface-based ducts on the clutter power level are not modeled in EREPS.

The GIT model gives the clutter cross-section, in decibels relative to 1-square meter, as

$$\sigma_c = \sigma^\circ + A_c \tag{136}$$

where σ° is the average clutter cross section per unit area (dB) and A_c is the area of the radar resolution cell (dB). σ° is a polarization-dependent variable. For a horizontally polarized radar, it is given as

$$\sigma^\circ{}_H = 10\mathrm{LOG}_{10}\left(3.9 \cdot 10^{-6}\,\lambda\;\psi^{0.4}\,A_i\,A_u\,A_w\right) \tag{137}$$

and for a vertically polarized radar

$$\begin{aligned}\sigma^\circ_V = {} & \sigma^\circ_H - 1.05\mathrm{LOG}_e\left(h_{avg} + 0.02\right) + 1.09\mathrm{LOG}_e(\lambda)\\ & + 1.27\mathrm{LOG}_e\left(\psi + 10^{-4}\right) + 9.7 \qquad \text{for } f \geq 3000 \text{ or}\end{aligned} \tag{138}$$

$$\begin{aligned}\sigma^\circ_V = {} & \sigma^\circ_H - 1.73\mathrm{LOG}_e\left(h_{avg} + 0.02\right) + 3.76\mathrm{LOG}_e(\lambda)\\ & + 2.46\mathrm{LOG}_e\left(\psi + 10^{-4}\right) + 22.2 \qquad \text{for } f < 3000.\end{aligned} \tag{139}$$

ψ is the grazing angle, (see figure 6-1), h_{avg} is the average wave height in meters and λ is the EM wavelength. σ°_C for a circularly polarized system is suggested by Nathanson (1969) as

$$\sigma^\circ_C = \sigma^\circ_{\max} - 6 \tag{140}$$

where $\sigma^\circ_{\max}$ is the larger of σ°_H or σ°_V as calculated above. Equation 134 is applicable for grazing angles between 0.1 degree and 10 degrees.

The dependence of σ° on sea state is more strongly a function of wind speed than wave height. However, in EREPS, the wave height is assumed to be only a function of wind speed. Thus, the average wave height is given by

$$h_{avg} = \left(\frac{W_s}{8.67}\right)^{2.5}, \tag{141}$$

where W_s is the wind speed in meters per second.

The wind speed factor, A_w, is determined using

$$A_w = \left[\frac{1.9425\,W_s}{1+\frac{W_s}{15}}\right]^{1.1(\lambda+0.02)^{-0.4}}. \tag{142}$$

The interference term, A_i, is defined as

$$A_i = \frac{\sigma_\phi^4}{1+\sigma_\phi^4}, \tag{143}$$

where σ_ϕ is a roughness parameter given by

$$\sigma_\phi = \frac{(14.4\lambda+5.5)\psi\ h_{avg}}{\lambda}. \tag{144}$$

The upwind/downwind factor, A_u, is determined using

$$A_u = e^{\left[0.2\mathrm{COS}(\phi)(1-2.8\psi)(\lambda+0.02)^{-0.4}\right]}, \tag{145}$$

where ϕ is the angle between the radar antenna boresight and the upwind direction (0 to 180 degrees).

The area of the radar clutter resolution cell, A_c, is calculated using

$$A_c = 10\mathrm{LOG}_{10}\left[\frac{1000\, r\, c\, \Theta_H\, \tau_c}{4\mathrm{LOG}_e(2)}\right], \tag{146}$$

where r is the range in kilometers, c the speed of light in meters/second, τ_c the radar system compressed pulse width in seconds, and Θ_H is the radar antenna horizontal beamwidth in radians.

For frequencies below 2 GHz, the GIT model is used without alteration for grazing angles in the range 0.1 to 10 degrees. The maximum range where equation 136 is applicable is determined using

$$R_{\mathrm{lim}} = 0.5\left[-2\, \psi\, a_e + \sqrt{(2\, \psi\, a_e)^2 + 0.008\, H_t\, a_e}\right], \tag{147}$$

where the grazing angle ψ = 0.001745 radians (0.1 degree). The grazing angle for any range less than R_{lim} is determined by

$$\psi = \frac{H_t}{1000r} - \frac{r}{2a_e} \text{ (radians)} \tag{148}$$

for all $\psi \leq 10$ degrees. The launch angle, α, associated with each of these values of ψ is given by equation 23 with the H_r term equal to zero.

At radar frequencies of 2 GHz and greater, the maximum range analogous to equation 147 is determined using a raytrace for the evaporation duct profile. The limiting ray for this case is the ray launched at the transmitter height that intersects the surface at the farthest possible range. This ray has a launch angle equal to

$$\alpha = 10^{-3}\sqrt{2(M_{Ht} - M_{\min})^2} - 10^{-6} \qquad \text{for } H_t < \delta, \text{ and} \tag{149}$$

$$\alpha = -10^{-3}\sqrt{2(M_{Ht} - M_{\min})^2} - 10^{-6} \qquad \text{for } H_t \geq \delta, \tag{150}$$

where M_{Ht} is the M-unit value at H_t, and $M_{\min}$ is the minimum value on the evaporation duct height profile ($M_{\min}$ is determined using equation 153 with $z = \delta$). The profile is then used to trace rays to determine range for all ranges less than $R_{\lim}$ such that $\psi \leq 10$ degrees. The grazing angle associated with α is determined using

$$\psi = \sqrt{\alpha^2 - 2(M_{Ht} - M_s)10^{-6}} \tag{151}$$

for all ranges less than $R_{\lim}$.

The clutter level for ranges beyond $R_{\lim}$ is determined using the average clutter cross-section, $\sigma°$, at $R_{\lim}$. The reflectivity at this limiting grazing angle is modified using the evaporation duct attenuation rate from equation 98. That is

$$\sigma° = \sigma°_{\lim} - 2\beta r \qquad \text{for } r > R_{\lim} . \tag{152}$$

where $\sigma°_{\lim}$ denotes the value of $\sigma°$ at the limiting grazing angle associated with $R_{\lim}$ determined from equation 148 or 151.

Raytracing

Environmental Profiles

All EREPS programs employ a raytrace, in one form or another, to determine various parameters. To accomplish the raytrace, the atmosphere's refractive structure is described by an environmental profile, defined by an array (H) of ascending heights and a corresponding array (M) of M-unit values. For the RAYS program only, two adjacent heights may be equal with the corresponding M-unit values at these heights also being equal. The M-unit profile is constructed such that the M-unit value at the surface, (zero height) is the first element in the M array.

In PROPR, PROPH, and COVER, the raytrace is used to determine the skip zone effects for a surface-based duct. The profile is created internally to the programs from your input of surface-based duct height, effective earth radius factor, and surface refractivity.

The surface-based duct model assumes the upper 10 percent of the surface-based duct is the trapping layer. Below the trapping layer, the refractivity gradient is set equal to the inverse of the effective earth radius ($dMdh = 0.001a_e^{-1}$). The gradient within the trapping layer is calculated from the assumption that the M-unit value at the top of the duct is equal to M-unit value at the surface, M_s. At the surface, M-units = N-units (the EREPS *NSUBS* input value).

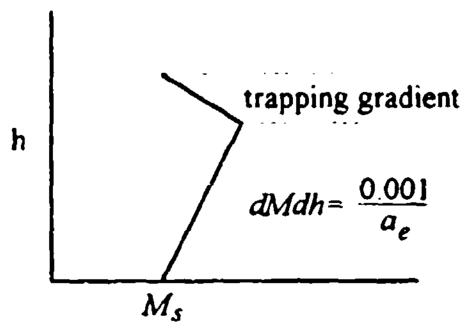


Figure 6-5: Surface-based Duct Model

PROPR and PROPH use a raytrace to determine a range for calculating clutter cross-sections under evaporation ducting conditions. Again, the profile is created internally to the programs from your input of evaporation duct height. In constructing the evaporation duct profile, neutral stability is assumed and the M-value at any height, h, is calculated using

$$M(h) = M_s + \frac{h}{8} - \left(\frac{\delta}{8}\right)\mathrm{LOG}_e\left[\frac{h+0.00015}{0.00015}\right], \tag{153}$$

where M_s is equal to the M-unit value at the surface and δ is the evaporation duct height. The profile is created by using equation 153 for the heights of 0.135, 0.368, 1.0, 2.7, 7.4, 20.1, and 54.6 meters, as well as δ and H_t, for H_t < 54.6. If H_t > 54.6, its height is appended to the profile by using a standard atmospheric gradient of 118 M/km upward from 54.6 meters.

RAYS produces a raytrace diagram and requires you to enter the profile directly or, in the range-dependent case, read the profiles' description from an ASCII text file. Up to 50 vertical segments per profile are allowed, and for the range-dependent case, you may enter as many as 15 such profiles at irregular ranges.

In addition to height and M-unit entries, RAYS also allows you to enter profile data graphically: by specifying duct and layer characteristics; by height and N-units; by pressure, temperature, and moisture, where the moisture may be relative humidity, dew-point temperature, or dew-point depression temperature; and by World Meteorological Organization code. The models that relate N, pressure, temperature, and moisture to M

are taken from Berry (1945), and Bean and Dutton (1968). The models are given by equations 2 through 5 of chapter 2.

Evaporation Duct Height

In addition to the environmental input methods described above, RAYS also lets you enter surface bulk meterological observations (air temperature, T_a, sea-surface temperature, T_s, relative humidity, RH, and wind speed, u) to create an evaporation duct profile. For reference, the subscript a refers to air temperature in Celsius, the subscript s refers to sea-surface temperature in Celsius and any appended subscript k refers to either temperature in Kelvin. As an alternative to bulk observations, you may specify the evaporation duct height directly and an associated stability parameter (either the bulk Richardson's number or the Monin-Obukhov length) to obtain the evaporation duct profile. The models for the calculation of evaporation duct height and evaporation duct height profiles are taken from Jeske (1965, 1971, and 1973).

If you enter bulk meteorological observations, an evaporation duct height must be determined prior to creating the profile. If the wind speed is less than 0.01 knot, the evaporation duct height is set to zero. If not, the following four steps are taken.

<u>Step 1</u>: A bulk Richardson's number is calculated as

$$Ri_b = 369\,h_1 \frac{T_a - T_s}{u^2\,T_{ak}} , \qquad (154)$$

where h_1 is a measurement reference height (taken to be 6 meters) and Ri_b is restricted to being no greater than 1.

<u>Step 2</u>: From the Richardson's number, a Monin-Obukhov length is determined as

$$L' = \frac{10\,h_1\,\Gamma_e}{Ri_b} , \qquad (155)$$

with the Γ_e function given by

$$\Gamma_e = 0.05 \qquad \text{for } Ri_b \leq -3.75, \qquad (156)$$

$$\Gamma_e = 0.065 + 0.004 Ri_b \qquad \text{for } -3.75 < Ri_b \leq -0.12. \qquad (157)$$

$$\Gamma_e = 0.109 + 0.367 Ri_b \qquad \text{for } -0.12 < Ri_b \leq \qquad (158)$$

$$\Gamma_e = 0.155 + 0.021 Ri_b \qquad \text{for } 0.14 < Ri_b. \qquad (159)$$

Step 3: A potential refractivity difference between the air and the sea surface is determined from

$$\Delta N_p = N_a - N_s \, , \qquad (160)$$

with the refractivity of the air at the reference height and at the sea surface given by

$$N_a = \frac{77.6}{T_{ak}}\left[1000 + \frac{4810}{T_{ak}} e\right] \text{ and} \qquad (161)$$

$$N_s = \frac{77.6}{T_{sk}}\left[1000 + \frac{4810}{T_{sk}} e_o\right] \text{, respectively,} \qquad (162)$$

the ambient vapor pressure of the air being

$$e = \frac{RH}{100}\left[6.105 \mathrm{EXP}\left[25.22\left(\frac{T_{ak} - 273.2}{T_{ak}}\right) - 5.31 \mathrm{LOG}_e\left(\frac{T_{ak}}{273.2}\right)\right]\right] \text{ and} \qquad (163)$$

a vapor pressure at the sea surface of

$$e_s = 6.105 \mathrm{EXP}\left[25.22\left(\frac{T_{sk} - 273.2}{T_{sk}}\right) - 5.31 \mathrm{LOG}_e\left(\frac{T_{sk}}{273.2}\right)\right]. \qquad (164)$$

Step 4: The stability conditions are now examined to determine which form the evaporation duct height equation will take. For thermally neutral and stable conditions ($0 \leq Ri_b \leq 1$), the evaporation duct height is given as either

$$\delta = 0 \qquad \text{for } \Delta N_p \geq 0, \text{ or} \qquad (165)$$

$$\delta = \frac{\Delta N_p}{-0.125\left(\mathrm{LOG}_e\left(\frac{h_1}{h_0}\right) + \frac{5.2h_1}{L'}\right) - \frac{5.2\,\Delta N_p}{L'}}, \text{or} \tag{166}$$

if the results of equation 166 give $\delta < 0$ or $\frac{\delta}{L'} > 1$, then

$$\delta = \frac{\Delta N_p(1 + 5.2) + 0.65\,h_1}{-0.125\mathrm{LOG}_e\left(\frac{h_1}{h_0}\right)}, \tag{167}$$

where h_0 is the aerodynamic surface roughness parameter (taken to be 0.00015 meter).

If thermally unstable conditions ($Ri_b < 0$) exist, the evaporation duct height is given as

$$\delta = \frac{1}{\sqrt[4]{A^4 - \frac{18}{L'}A^3}}, \text{ where} \tag{168}$$

$A = \frac{-0.125B}{\Delta N_p}$, $B = \mathrm{LOG}_e\left(\frac{h_1}{h_0}\right) - \psi$, and the universal function, ψ, is given by Lumley and Panofsky (1964), as

$$\psi = -4.5\frac{h_1}{L'} \qquad \text{for } \frac{h_1}{L'} \geq -0.01\ , \tag{169}$$

$$\psi = 10^{\left[1.02\mathrm{LOG}_{10}\left(\frac{-h_1}{L'}\right)+0.69\right]} \qquad \text{for } -0.01 > \frac{h_1}{L'} \geq -0.026, \tag{170}$$

$$\psi = 10^{\left[0.776\mathrm{LOG}_{10}\left(\frac{-h_1}{L'}\right)+0.306\right]} \qquad \text{for } -0.026 > \frac{h_1}{L'} \geq -0.1, \tag{171}$$

$$\psi = 10^{\left[0.630\mathrm{LOG}_{10}\left(\frac{-h_1}{L}\right)+0.16\right]} \qquad \text{for } -0.1 > \frac{h_1}{L} \geq -1.0, \tag{172}$$

$$\psi = 10^{\left[0.414\mathrm{LOG}_{10}\left(\frac{-h_1}{L}\right)+0.16\right]} \qquad \text{for } -1.0 > \frac{h_1}{L} \geq -2.2 \text{ and,} \tag{173}$$

$$\psi = 2 \qquad \text{for } \frac{h_1}{L} < -2.2. \tag{174}$$

The dominant factor in determing evaporation duct height is the difference in potential refractivity between the air at the reference altitude and the air at the sea surface. Errors in air temperature measurements caused by conductive and radiative heating effects have been shown to strongly affect the duct height calculation. RAYS allows you to account for these errors by applying a Paulus (1989) adjustment technique. For this technique, an additional test is made whenever $(T_a - T_s) > -1$. An evaporation duct height (δ_0) is calculated with $T_a = T_s$ and a second evaporation duct height (δ_{-1}) for $T_a = T_s - 1$, keeping T_s, u, and RH unchanged. If $\delta_0 > \delta_{-1}$, the value of δ_{-1} is used as the evaporation duct height. Otherwise, the evaporation duct height is calculated using steps 1 through 4 above.

Evaporation Duct Profiles

Once an evaporation duct height and stability parameter are determined, either entered directly or calculated from the bulk metoeorological parameters described above, then for neutral conditions the profile is calculated from equation 153.

For stable conditions the profile is given by

$$M(h) = M_s + \frac{h}{8} - \left(\frac{0.125\delta}{1+\frac{5.2\delta}{L}}\right)\mathrm{LOG}_e\left[\frac{h+h_0}{h_0} + \frac{5.2h}{L}\right] \tag{175}$$

in terms of variables as defined above. For unstable conditions, the profile is calculated as

$$M(h) = M_s + \frac{h}{8} - \left(\frac{0.125\delta}{\phi\left(\frac{\delta}{L}\right)} \right) \mathrm{LOG}_e \left[\frac{h + h_0}{h_0} + \psi\left(\frac{\delta}{L}\right) \right], \qquad (176)$$

where the stability dependent function, $\phi\left(\frac{\delta}{L}\right)$, is computed using a Newton iteration to solve the equation

$$\phi^4 - 20.8\frac{h}{L}\phi^3 = 1. \qquad (177)$$

Rather than using the nine fixed heights, h, associated with the evaporation duct height profile described for PROPR, PROPH, and COVER (equation 153), RAYS computes the evaporation duct profile at heights of e^h, where h steps upward from -2 to 5 in 0.5 steps or until a standard M-unit gradient is achieved.

Raytrace Equations

The raytrace equations are based on small angle approximations to Snell's law and the assumption of a linear variation of modified refractivity, M, with height. For these equations, heights are in meters, ranges are in kilometers, and angles are in radians. Rays that reflect from the sea surface are assumed to have equal incident and reflected angles.

At each step within the raytrace, a M-unit gradient is needed. For PROPR, PROPH, and COVER and the range-independent case of RAYS, only the vertical gradient is considered and is given as

$$dMdh_j = 10^{-3}\frac{(M_{j+1} - M_j)}{H_{j+1} - H_j}, \qquad (178)$$

where the M_j denotes the jth vertical element in the M-unit array, and the H_j denotes the corresponding jth vertical element in the the height array.

For the range-dependent case of RAYS, both a vertical and a horizontal gradient is considered and is given as

$$dMdh_{i,j} = 10^{-3}\frac{(M_1 - M_0)}{H_1 - H_0} \quad (179)$$

The M-unit and height values of equation 179 (as illustrated in the following figure) are determined at a range, r_m, midpoint between the current range and the range at the next range step. These values are

$$M_0 = M_{i,j} + K\left(M_{i+1,j} - M_{i,j}\right), \quad (180)$$

$$M_1 = M_{i,j+1} + K\left(M_{i+1,j+1} - M_{i,j+1}\right), \quad (181)$$

$$H_0 = H_{i,j} + K\left(H_{i+1,j} - H_{i,j}\right), \text{ and} \quad (182)$$

$$H_1 = H_{i,j+1} + K\left(H_{i+1,j+1} - H_{i,j+1}\right), \quad (183)$$

where the proportionality constant, K, as a function of profile ranges, r_i, is given by

$$K = \frac{r_m - r_i}{r_{i+1} - r_i}. \quad (184)$$

The index i refers to the horizontally spaced profiles, and the index j refers to the vertical levels within the profile.

Negative values of $dMdh_j$ are trapping layers. A standard atmosphere (4/3 earth) gradient is defined for the gradient above the highest height array element, that is, $dMdh_{j+1}$ = 0.000118, where j is the index of the last element in the H array. For the RAYS program only, $dMdh_j$ values of zero are allowed.

Raytrace equations using height, M-units, and M-unit gradients can be divided into three cases: rays with the terminal range r' known, rays with the terminal height H' known, and rays with the terminal elevation angle α' known.

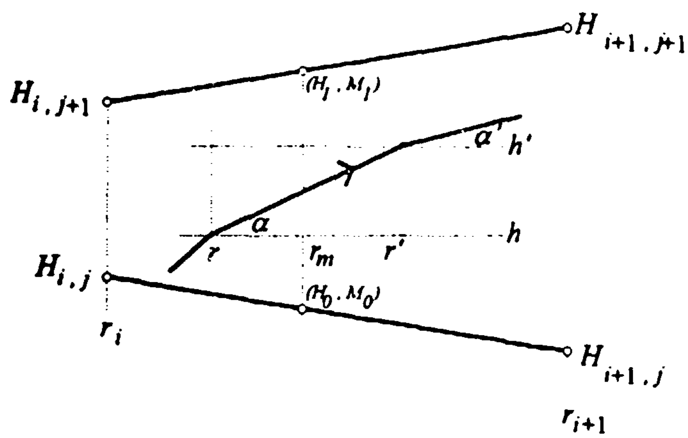


Figure 6-6: Raytrace variables.

While the figure 6-6 illustrates a range- dependent ray (sloping layers) with a positive launch angle, the equations also apply to negative launch angles when proper care is taken with respect to the layer indices and sign of the launch angle. The equations apply only to range and height values within individual layers.

Case 1: h' known with $\alpha \neq 0$.

$$\alpha' = \sqrt{\alpha^2 + 0.002\, dMdh_j (h' - h)} \tag{185}$$

$$r' = r + \frac{\alpha' - \alpha}{dMdh_j} \tag{186}$$

Case 2: r' known with $\alpha \neq 0$.

$$\alpha' = \alpha + (r' - r) dMdh_j \tag{187}$$

$$h' = h + \frac{\alpha'^2 - \alpha^2}{0.002\, dMdh_j} \tag{188}$$

Case 3: α' known.

$$r' = r + \frac{\alpha' - \alpha}{dMdh_j} \tag{189}$$

$$h' = h + \frac{\alpha'^2 - \alpha^2}{0.002\, dMdh_j} \tag{190}$$

If the radicand of equation 185 is negative, there is no solution for the given height h' since the ray has reached a maximum (or, in the case of a downgoing ray, a minimum) height less (greater) than h. In this case, $\alpha = 0$, and the range and height of the ray maximum (minimum) are

$$r' = r - \frac{\alpha}{dMdh_j} \quad \text{and} \tag{191}$$

$$h' = h - \frac{\alpha}{0.002\, dMdh_j} \quad . \tag{192}$$

One unique case not covered by the above equations is the case when $\alpha = 0$. If $dMdh_j > 0$, the ray will become an upgoing ray. If $dMdh_j < 0$, the ray will become a downgoing ray. If $dMdh_j = 0$ (for the RAYS program), the ray will not refract but will remain parallel to the earth's surface.

Radar Models

PROPR, PROPH, and COVER all contain the ability to calculate free-space range from radar system parameters such as frequency, pulse length, etc. PROPR and PROPH can also calculate ESM free-space intercept and communications intercept ranges. The models to do this calculation are taken from Blake (1980).

Three types of radar calculations are allowed by the program: *simple*, *integration*, and *visibility factor*. A *simple* type calculation is normally used for a rotating, pulsed radar that uses noncoherent pulse integration to increase its sensitivity. The signal-to-noise ratio required for a given probability of detection and false alarm rate is known as either the visibility factor or the detectability factor, D_o. For a simple radar with a uniform-weight integrator and a square-law detector, D_o is

$$D_o = \frac{L_f x_o}{4 N_p}\left(1 + \sqrt{1 + \left(\frac{16 N_p}{x_o}\right)}\right), \tag{193}$$

where

$$x_o = \left(g_{fa} + g_d\right)^2 , \tag{194}$$

$$g_{fa} = 2.36\left[-\mathrm{LOG}_{10}\left(P_{fa}\right)\right]^2 - 1.02\,, \tag{195}$$

$$g_d = 1.23t\sqrt{1-t^2}\,, \text{ and} \tag{196}$$

$$t = 0.9(2P_d - 1)\,. \tag{197}$$

Here, N_p is the number of pulses integrated by the detector (hits per scan), L_f is the fluctuation loss, P_d is the probability of detection, and P_{fa} is the probability of false alarms. For the simple radar,

$$N_p = \frac{\Theta_H f_p}{6\phi_h}, \tag{198}$$

where Θ_H is the horizontal beam width in degrees, f_p is the pulse repetition frequency in Hertz, and ϕ_h is the horizontal scan rate in revolutions per minute. The fluctuation loss, L_f, is 1 for a Swerling Case 0, nonfluctuating target. If a fluctuating target is selected, L_f is calculated for a Swerling Case 1, kF = 1, chi-square target

$$L_f = \frac{1}{-\mathrm{LOG}_e(P_d)\left(1 + \dfrac{g_d}{g_{fa}}\right)}. \tag{199}$$

While equation 193 assumed a square-law detector, the difference between square-law detectors and the more commonly used linear detectors is generally less than 1 dB.

D_o for the integration type radar where coherent integration is used is given by

$$D_o = \frac{L_f x_o}{4N_p}\left(1 + \sqrt{1 + \left(\frac{16}{x_o}\right)}\right). \tag{200}$$

where all quantities have been previously defined. If the radar calculation type is set to visibility factor, then the user must supply the value of visibility factor to be used in place

of equation 193. This option may be the most useful to users dealing with modern sophisticated radar systems that use complicated signal processing schemes.

Blake's (1980) equation 1.34 is used to calculate the radar free-space detection range. The bandwidth correction factor, C_b, of equation 1.34 was arbitrarily set to 1, and the system noise temperature set to 290° K. With some algebra, this equation becomes

$$R_{fs} = 58 \sqrt[4]{\frac{P_t \, \sigma \, \tau \, Z}{f^2}} \quad \text{(km)}, \tag{201}$$

where P_t is the transmitter power in kilowatts, σ is the target cross-section in square meters, τ is the pulse width in microseconds, f is the radar frequency, and Z is a function of several radar parameters. Z is given by

$$Z = 10^{\frac{2G - N_f - D_o - L_s}{10}}, \tag{202}$$

where G is the antenna gain in decibels, N_f is the receiver noise figure in decibels, D_o is previously defined, and L_s is the miscellaneous system losses in decibels. All losses not specifically mentioned above must be accounted for in the system losses, such as transmission line loss, filter mismatch loss, signal processing loss, beam-shape loss, etc. The free-space range threshold for PROPH or PROPR can be obtained by substituting the range from equation 201 into equation 12.

The radar target signal-to-noise ratio is derived from target signal power calculated from Blake's equation 1.18. The received target power in decibels referenced to a Watt is

$$P_r = -73.4 + 10\mathrm{LOG}_{10}\left[\frac{P_t \, \sigma \, F^4}{f^2 \, r^4}\right] + 2G - L_s, \tag{203}$$

where r is the range, F is the pattern propagation factor, and all other terms are as previously defined. The signal-to-noise ratio is equal to the target power received divided by the system noise power, which in decibels is

$$S/N = P_r - P_n. \tag{204}$$

where P_r is the received target power and P_r is the system noise power in decibels referenced to a Watt. The noise power is a function of the pulse width and the receiver noise figure given by equation 125.

ESM Models

The propagation threshold for ESM systems is calculated as the decibel difference between the effective radiated power and the ESM receiver sensitivity, as adjusted by appropriate system losses. For transmitter peak power P_t in kilowatts, transmitter antenna gain G in decibels above isotropic, ESM system sensitivity S in decibels referenced to a milliwatt, and system losses L_s and propagation threshold T in decibels, is calculated as

$$T = 10\mathrm{LOG}_{10}(P_t) + 60 + G - S - L_s. \tag{205}$$

For example, if P_t = 100 kW, G = 30 dBi, S = -80 dBm, and L_s = 5 dB, then T = 185 dB. Normally, ESM system sensitivity includes receiving antenna gain and line losses. Thus L_s would be used to account for the transmission line loss and other losses associated with the transmitter. Under PROPR and PROPH display option 2, the threshold loss T is plotted on the propagation-loss display as a horizontal and vertical dashed line, respectively. Propagation losses less than the threshold correspond to intercept capability.

The same display option and system parameters may be used to assess communications systems. The only difference is that system sensitivity should be adjusted to account for the signal-to-noise ratio margin associated with a given level of communications quality.

Implementation of the Models

PROPR

PROPR presents propagation loss (or other quantities already described) versus range, showing sufficient detail to clearly define the structure of optical region lobes and other relevant propagation mechanisms. The construction of the propagation loss diagram involves both the propagation models as described above and the number of horizonal screen pixels on your monitor. EREPS runs exclusively in EGA-mode, and the length of the range axis is designed for 432 pixel points. Therefore, each horizontal pixel point is associated with a known range. The program begins by determining the maximum range for which the optical region calculations are valid. Starting at this range, the optical region propagation loss is determined for each shorter *pixel point* in range, up to the maximum number of optical region lobes to be plotted. If the range step to the next pixel point is large enough to step past an optical region null (or peak), then PROPR determines the range where that value occurs and plots it before plotting the value at the pixel point range. It is possible to select a maximum plot range that is too short to display the specified number of lobes since the lobe count starts with the first lobe that can be plotted at the optical region maximum range. If the plot range is too large, it is possible that the lobes will not be distinct since each pixel point may encompass several lobes.

After the optical region computations are completed, the minimum valid range for diffraction models, r_d, is found. Linear interpolation of the pro on factor in decibels is used between the last point in the optical region and the fi it in the diffraction region.

For ranges at and beyond r_d, the applicable diffraction, ducting, and/or troposcatter models are used. For all ranges beyond the optical limit, surface-based duct loss is computed (for duct heights greater than zero) and is used when it is less than the loss from the other models. At all ranges within PROPR, water vapor attenuation loss is computed and added to the other losses. At ranges beyond the optical limit, a range increment of 1/100th the total plotted range is used.

PROPH

PROPH presents propagation loss (or other quantities already described) versus receiver height at a fixed range. The first step is to determine the receiver height at the optical limit, in a similar manner as described for PROPR. Computations for each lobe in the optical region are made to determine the next higher receiver height corresponding to a null using a Newton-method iteration. The height interval between successive nulls is split into multiple segments for which loss is computed and plotted. For each height below the optical limit, a check is made to determine if the fixed range exceeds the minimum valid range for diffraction. If it is, the appropriate diffraction, ducting, and/or troposcatter model is used. Otherwise, linear interpolation is used on the propagation factor in decibels between the optical-limit maximum range and the diffraction-region minimum range at the current receiver height. As with PROPR, at heights below the optical limit, the lesser loss from the surface-based duct model (for non-zero duct heights) and the other models is used. At all heights, the water vapor attenuation is added to the loss. Note that in PROPH the independent variable is receiver height for all calculations, with the increment being set to 1/300th of the maximum plotted height in the optical region, 1/10th of the height between the optical and diffraction limits in the interpolation region, and the greater of 2 meters or 1/300th of the maximum plotted height otherwise.

COVER

COVER presents an altitude-versus-range contour that defines an area within which propagation loss will always be less than a specified value. In the optical region, an assumption has been made that the ray path between the transmitter and receiver is parallel to the ray path from the reflection point to the receiver. This assumption is quite good at long ranges, but can be in substantial error at short ranges and low receiver altitudes. However, it results in the propagation factor being a constant for any elevation angle, which, in turn, permits fast and easy computation of the maximum range at that angle. When applying COVER to short ranges and low receiver heights, it is a good idea to check the results with PROPR. If there is a substantial difference in results, PROPR is the model to use.

The COVER algorithm begins by determining the elevation angle at the optical limit. In the optical region, a Newton-method iteration is used to find the next higher

elevation angle corresponding to a predetermined phase angle between the direct and reflected paths. Fourteen such phase angles are used per lobe to give good definition to the shape of the lobes. After the required lobes have been completed, an *envelope* contour of the ranges at the maximum of all higher-angle lobes is drawn up to an angle that depends on the antenna pattern and beamwidth selected. For heights and ranges below the optical limit, the independent variable is receiver height. For ducting conditions, a sufficiently small height increment is used to give good definition to the vertical height-gain factors. Otherwise a height increment of 1/20th of the total plot height is used. All contours created by each lobe, the envelope region, and the over-the-horizon region are filled with a single shade and color. Water vapor absorption is included in the optical region through an iterative solution of maximum range, and in the beyond-horizon region through addition of the absorption loss to the diffraction or ducting losses. Troposcatter effects are not considered in COVER, since they will almost always be at such high values as to not affect the coverage diagram.

RAYS

RAYS presents a series of ray-path trajectories on a height-versus-range display. You must specify the refractive-index profile, the transmitter height, the elevation angle limits, and number of rays desired. Each ray is traced based on a series of range-step calculations that are performed within each refractivity layer specified in the profile. Beginning at a range of zero and a height equal to the transmitter height, with a launch angle that is a function of the beamwidth and number of rays to trace, and a M-unit gradient interpolated at the starting height and range, the raytrace algorithm steps in range. An ending angle and height are calculated. The ending height is examined to see if it is outside of the current layer. If the ray leaves the current layer, then the range to the layer boundary at the boundary height is calculated, and an ending angle at the ray/boundary intersection is recomputed. As each range step is taken, the refractivity gradient must be computed for use in the next range step. For the range-independent case, this gradient is computed only once at the layer boundary and is used for each range step within the layer. For the range-dependent case, the gradient is computed at every range step. Tests must be included to determine if the ray has reached a maximum or minimum height, to ensure that the corresponding elevation angle of zero is considered. Additional tests are made to ensure a range step does not carry past a profile range. If a

range step encompasses a new profile, the step size is adjusted smaller to equal the distance from the step's beginning range to the profile's range.

For the altitude-error option, a second raytrace for a standard atmosphere is computed at each point along the ray, such that the altitude difference between the actual and standard ray paths can be determined. The color of each ray segment is then determined based on the altitude difference and your defined scale.

FFACTOR

The FFACTOR subroutine returns a single value of the propagation factor in decibels for a series of specified system, geometry, and environmental parameters. The first step is to calculate the optical limit range If the specified range is less than the optical limit, a solution to the cubic equation to determine the reflection point in the optical region is performed along with all other optical region calculations to determine the propagation factor. If the specified range is greater than the optical limit, the minimum range for valid diffraction calculations is determined. If the specified range is between these two limits, linear interpolation of the propagation factor in decibels versus range is performed to compute the desired result. For ranges beyond the minimum diffraction range, the appropriate diffraction, ducting, and/or troposcatter model is used. For all ranges beyond the optical limit, the lesser loss of the surface-based duct model (for non-zero duct heights) and the other applicable models is used. At all ranges, the loss from water vapor absorption is added.

FFACTOR Subroutine Source Code

```
' **************************************************************

' Subroutine:  FFACTR                    Date:  03/09/94

' **************************************************************

' Process:

'   For electromagnetic systems, computes the pattern propagation factor in
'   decibels for a specified range.  Positive values indicate a signal level
'   above the free-space field strength.  Negative values indicate a signal
'   level below free-space field strength.

' **************************************************************

' Subroutines:            Microsoft BASIC functions
'     antpar                  abs
'     antpat                  atn
'     dconst                  cos
'     difint                  exp
'     dloss                   log (natural)
'     GetTheta                sin
'     hgain                   sqr
'     opconst                 swap
'     opffac                  tan
'     opticf
'     oplimit
'     r1iter
'     ref
'     ruff
'     sbd
'     skipzone
'     tropo

' When calling subroutines within FFACTR, convention is to use
' lower case variable names for the input parameters and upper
' case variable names for the returned parameters.
```

```
' Input parameters:
'
'    Electromagnetic system:
'       antyp$  -  Antenna type
'                     OMNI        - Omnidirectional
'                     SINX/X      - SIN(X)/X
'                     GAUSS       - Gaussian beam
'                     CSC-SQ      - Cosecant-squared
'                     HT-FINDER   - Generic height finder
'       bwidth  -  Antenna beam width
'                     GAUSS - (0.5 - 35.0 degs)
'                     SINX/X, CSC-SQ, HT-FINDER -  (0.5 - 45 degs)
'       elevat  -  Antenna elevation angle  (-10.0 to +10.0 degs)
'                     0 deg is horizontal, normal pointing angle for
'                     shipboard radar systems
'       freq    -  Frequency   100 - 20000 MHz
'       hr      -  Receiver/target height  (1 - 10000 m)
'       ht      -  Transmitter antenna height  (1 - 10000 m)
'                     one of the above terminal heights should
'                     be < 100 m for pulsed systems
'       polar$  -  Antenna polarization
'                     H - horizontal
'                     V - vertical
'                     C - circular
'       r       -  Desired range for F-Factor  (1 - 1000 km)
'
'    Environmental:
'       delta   -  Evaporation duct height  (0 - 40 m)
'       humid   -  Absolute humidity   (0 - 14 grams/m^3)
'                     World average is 7.5 grams/m^3
'       rk      -  Effective earth radius factor (1.0 - 5.0)
'                     4/3 is a "standard" atmosphere
'       rnsubs  -  Surface refractivity   (0 - 450)
'                     World average is 339 N-units
'       sbdht   -  Surface-based duct height  (0 - 1000 m)
'       wind    -  Surface wind velocity  (0 - 100 KNOTS)
'
' ****************************************************************
'
'Output parameter:
'       ff      -  20*LOG10(Pattern propagation factor) in dB
'                     ff values that are positive indicate a
'                     signal level above the free-space field
'                     at that range. Negative values indicate
'                     signal levels below the free-space field.
```

```
' ***********************************************************************

' The following program is a demonstration driver for the FFACTR subroutine.
' It is included to show possible uses for the FFACTR subroutine. The FFACTR
' subroutine is structured to return a value (in dB) representing the ratio of the
' actual field strength at a range, to the free-space field strength at that same range.
' Because the FFACTR subroutine may be called in any arbitrary fashion, it is not
' the most efficient structure for producing a product such as a loss-versus-range
' (or height). If only the range is to be varied, with constant terminal heights, a
' commom application, the OPCONST and the DCONST subroutine calls should
' be made only once at the start of the application program. This would necessitate
' removing them from the FFACTR subroutine and placing them in the calling
' program.

' Three sets of input parameters and resulting pathloss and propagation factors are
' provided below for testing of this subroutine after a language conversion. This
' demonstration program calls FFACTR only with the first input set:

' Set 1: Input parameters and output values - standard atmosphere
'   Enivronmental:                Electromagnetic system:
'     Delta    = 0.0                 Antype$  = "SINX/X"
'     Humid    = 7.5                 Bwidth   = 2.0
'     Rnsubs   = 339.0               Elevat   = 0.0
'     Rk       = 4./3.               Freq     = 5600.0
'     Sbdht    = 0.0                 Hr       = 20.0
'     Wind     = 10.0                Ht       = 20.0
'                                    Polar$   = "H"

'   Range (km)   Propagation loss (dB)   Propagation factor (dB)
'     55.0            185.31                  -43.09
'     50.0            177.31                  -35.91
'     45.0            169.47                  -28.99
'     40.0            161.52                  -22.06
'     35.0            153.43                  -15.14
'     30.0            145.17                  - 8.21
'     25.0            136.66                  - 1.29
'     20.0            129.41                    4.03

' Set 2: Input parameters and output values 10m evaporation duct
'   Enivronmental:                Electromagnetic system:
'     Delta    = 10.0                Antype$  = "CSC-SQ"
'     Humid    = 7.5                 Bwidth   = 4.0
'     Rnsubs   = 339.0               Elevat   = 0.0
'     Rk       = 4./3.               Freq     = 9600.0
```

```
'       Sbdht     = 0.0          Hr        = 100.0
'       Wind      = 0.0          Ht        = 10.0
'                                Polar$    = "V"

'   Range (km)   Propagation loss (dB)   Propagation factor (dB)
'       55.0          145.29                  1.62
'       50.0          143.67                  2.41
'       45.0          141.97                  3.20
'       40.0          140.15                  3.99
'       35.0          140.91                  2.07
'       30.0          142.74                  -1.10
'       25.0          137.52                  2.54
'       20.0          133.03                  5.09


' Set 3: Input parameters and output values - 100m surface-based duct
'    Enivronmental:                Electromagnetic system:
'       Delta     = 10.0         Antype$   = "GAUSS"
'       Humid     = 7.5          Bwidth    = 4.0
'       Rnsubs    = 339.0        Elevat    = 0.0
'       Rk        = 2.1          Freq      = 400.0
'       Sbdht     = 100.0        Hr        = 50.0
'       Wind      = 20.0         Ht        = 10.0
'                                Polar$    = "C"

'    Range (km)   Propagation loss (dB)   Propagation factor (dB)
'       55.0          110.61                  8.69
'       50.0          115.61                  2.86
'       45.0          120.61                  -3.05
'       40.0          125.61                  -9.08
'       35.0          130.61                  -15.24
'       30.0          127.12                  -13.09
'       25.0          123.30                  -10.85
'       20.0          119.12                  -8.61

' Start demonstration program

DEFINT I-N
CONST PI = 3.14159
CONST version$ = "3.00"
CONST ver.date$ = "09 March 1994"

COMMON SHARED /comffactr/ ae, ae2, aeth, alpha, antbwr
COMMON SHARED /comffactr/ antelr, antfac, antyp$, atten
```

```
COMMON SHARED /comffactr/ bwidth, C1, C2, C3, C4, C5, C6, C7
COMMON SHARED /comffactr/ capk, del, delta, difac, dtot, elevat
COMMON SHARED /comffactr/ elmaxr, exloss, f3, fofz
COMMON SHARED /comffactr/ freq, fsloss, fsterm, h1, h2
COMMON SHARED /comffactr/ h14pil, h24pil, h24ae2, hbar
COMMON SHARED /comffactr/ hbfreq, hdif, hmin, horizn
COMMON SHARED /comffactr/ horizn1, hr, ht, humid, opmaxd
COMMON SHARED /comffactr/ opmaxl, patd, patrfac, polar$, psi
COMMON SHARED /comffactr/ psilim, r1lim, r1min, rk, rmag
COMMON SHARED /comffactr/ m2imag, m2real, ms2, msterm
COMMON SHARED /comffactr/ msubs, rsbd, rsbdloss, rsubd
COMMON SHARED /comffactr/ sbdht, tfac, thefac
COMMON SHARED /comffactr/ tsub1, tsub2, twoae, wind, wvatten
COMMON SHARED /comffactr/ xterm, zfac, zmax, zterm
antyp$ = "SINX/X"
bwidth = 2!
elevat = 0!
freq = 5600!
hr = 20!
ht = 20!
polar$ = "H"

delta = 0!
humid = 7.5
msubs = 339!
rk = 4!/3!
sbdht = 0!
wind = 10!
fsterm = 32.45 + 8.686 * LOG(freq)
dr = 5!
r = 60!
PRINT "--------------------------------------"
FOR i = 1 TO 8
     r = r - dr
     CALL FFACTR(freq, ht, hr, polar$, antyp$, bwidth, elevat, delta, sbdht, humid,
rk, msubs, wind, r, ff)
     rloss = fsterm + 2! * 4.343 * LOG(r) - ff
     PRINT r, rloss, ff
NEXT i
END

' End of demonstration program

' ******************************************************************
```

```
SUB FFACTR (freq, ht, hr, polar$, antyp$, bwidth, elevat, delta, sbdht, humid, rk,
rnsubs, wind, r, ff) STATIC

h1 = ht
h2 = hr
IF h1 > h2 THEN SWAP h1, h2                    ' swap antenna heights
r1min = .01 * r * h1 / (h1 + h2)               ' approximate r1 at 1% of range

'    Initialize antenna parameters
CALL antpar

'    Initialize optical region constants
CALL opconst
rkpsi = 1000! * psilim
wvloss = wvatten * r                           ' water vapor absorbtion loss

'    Initialize diffraction/troposcatter region constants
CALL dconst

'    Miscellaneous optical region variables
h24ae2 = h2 * 4! / ae2
hdif = (hr - ht) * .001
horizn1 = 3.572 * (SQR(rk * h1))
r1lim = (SQR(rkpsi * rkpsi + h1 * 4 / ae2) - rkpsi) * aeth

CALL oplimit(opmaxd, opmaxl, exloss)           ' max range in optical region

IF (r <= opmaxd) THEN

'    Calculate loss in the optical region
     CALL opticf(r, ff)
ELSE

'    Determine minimum range where diffraction calculations are valid, rsubd.
     rkmin = rk
     IF rkmin < 1.3333 THEN rkmin = 1.3333
     horiznmin = 3.572 * (SQR(rkmin * h1) + SQR(rkmin * h2))
     rsubd = horiznmin + 230.2 * (rkmin ^ 2 / freq) ^ (1! / 3!)

'    Calculate free-space loss value
     fsloss = fsterm + 8.686 * LOG(r)

'    Calculate range to skipzone if surface-based duct present
     IF (sbdht > 0!) AND (ht <= sbdht) THEN CALL skipzone(ht, hr)
```

```
'   CCIR Diffraction Model variables
    z1 = zterm * ht
    CALL GOFZ(z1, ght)
    z2 = zterm * hr
    CALL GOFZ(z2, ghr)
    dtot = fsterm - ght - ghr

'   NRaD Evaporation Duct Model variables
    IF (del > 0!) THEN
        CALL hgain(hr, DUMMY, fzr)
        CALL hgain(ht, DUMMY, fzt)
        difac = difac - fzt - fzr
    END IF

'   Troposcatter model variables
    tsub1 = SQR(ht * ae / 500) / ae
    tsub2 = SQR(hr * ae / 500) / ae
    h14pil = ht * .0419 * freq
    h24pil = hr * .0419 * freq
    horizn = 3.572 * (SQR(rk * h1) + SQR(rk * h2))

    IF (r > rsubd) THEN
'       Calculate loss in diffraction/troposcatter region
        CALL dloss(r, diff)
        IF (sbdht > 0) AND (sbdht > = ht) THEN
            CALL sbd(r, sbdloss)
            IF sbdloss < diff THEN diff = sbdloss
        END IF
        diff = diff - fsloss
        ff = diff
    ELSE
'       Calculate loss in intermediate region
        CALL difint(opmaxd, opmaxl, r, ff)
    END IF
END IF
ff = -(ff + wvloss)
END SUB
```

```
SUB antpar STATIC

' Process: Initialize antenna parameters
' Inputs from common block: antyp$, bwidth, elevat
' Outputs to common block: antbwr,antelr,antfac,elmaxr,patrfac
' Subroutines called: None
' Subroutine called by: FFACTR

antbwr = .01745 * bwidth
antelr = .01745 * elevat
elmaxr = 1.047
IF antyp$ < > "OMNI" THEN
     IF antyp$ = "GAUSS" THEN
          antfac = -LOG(2!) / (2! * SIN(antbwr / 2!) ^ 2!)
          patrfac = SIN(antelr)
          amax = SQR(10.11779 * SIN(antbwr / 2!) ^ 2!)
          elmaxr = antelr + ATN(amax / SQR(1! - amax ^ 2))
     ELSE
          IF antyp$ = "CSC-SQ" THEN
               elmaxr = antelr + .78525
               antfac = SIN(antbwr)
          ELSE
               IF (antyp$ = "SINX/X") OR (antyp$ = "HT-FINDER") THEN
                    antfac = 1.39157 / SIN(antbwr / 2!)
                    amax = PI / antfac
                    patrfac = -ATN(amax / SQR(1! - amax ^ 2))
                    IF antyp$ = "SINX/X" THEN elmaxr = antelr - patrfac
               END IF
          END IF
     END IF
END IF
END SUB
```

```
SUB antpat (angle, patfac) STATIC

' Process:  Calculate the normalized antenna pattern factor
' Inputs from common block:  alpha, antbwr, antelr, antfac, antyp$, patrfac
' Inputs from argument list:  angle
' Outputs to common block:  None
' Outputs to argument list:  patfac
' Subroutines called:  None
' Subroutine called by:  opffac

patfac = 1!
IF antyp$ < > "OMNI" THEN
     IF antyp$ = "HT-FINDER" AND alpha > antelr THEN
          alpha0 = alpha
     ELSE                          ' SINX/X or CSC-SQ or GAUSS
          alpha0 = antelr
     END IF
     apat = angle - alpha0
     IF antyp$ = "CSC-SQ" THEN
          IF apat > antbwr THEN
               patfac = SIN(antbwr) / SIN(ABS(apat))
          ELSEIF apat < 0 THEN
               patfac = 1! + apat / antbwr
               IF patfac < .03 THEN patfac = .03
          END IF
     ELSEIF antyp$ = "GAUSS" THEN
          IF apat > elmaxr OR angle < -elmaxr THEN
               patfac = .03
          ELSE
               patfac = EXP(antfac * (SIN(angle) - patrfac) ^ 2)
          END IF
     ELSE                        ' antyp$ is SIN(X)/X or HT-FINDER
          IF apat < > 0! THEN
               IF (apat < = patrfac) OR (-apat < = patrfac) THEN
                    patfac = .03
               ELSE
                    ufac = antfac * SIN(apat)
                    patfac = SIN(ufac) / ufac
                    IF patfac > 1 THEN patfac = 1
                    IF patfac < .03 THEN patfac = .03
               END IF
          END IF
     END IF
END IF
END SUB
```

```
SUB dconst STATIC

' Process: Initialize variables for the diffraction and troposcatter region
' Inputs from common block: ae, delta, freq, fsterm, h1, h2, rk, rnsubs
' Outputs to common block: atten, c1, c2, c3, c4, c5, c6, c7,
'          del, difac, dtot, f3, hmin, horizn, rnsterm, rns2,
'          tfac, xterm, zfac, zmax, zterm
' Subroutine called: hgain
' Subroutine called by: FFACTR

'   Troposcatter region constants
rnsterm = .031 - .00232 * rnsubs + 5.67E-06 * rnsubs ^ 2
tfac = .08984 / rk
   = freq ^ 3
     = .2 * rnsubs

'    CCIR diffraction region model constants
f13 = freq ^ (1! / 3!)
ae13 = ae ^ (1! / 3!)
sigfac = rn2imag ^ 2
rkfac = (2! * PI / .3) ^ (-1! / 3!) / (ae13 * f13)
rksubh = rkfac * ((rn2real - 1!) ^ 2 + sigfac) ^ (-1! / 4!)
betad = 1!
capk = rksubh

IF polar$ <> "H" THEN
     rksubv = rksubh * SQR(rn2real ^ 2 + sigfac)
     capk = rksubv
     IF freq < 300! THEN
          capksq = rksubv ^ 2
          betad = 1! + 1.6 * capksq + .75 * capksq ^ 2
          betad = betad / (1! + 4.5 * capksq + 1.35 * capksq ^ 2)
     END IF
END IF

xterm = 2.2 * betad * f13 * ae13 ^ (-2)
zterm = .0096 * betad * f13 ^ 2 / ae13

IF delta = 0! THEN                          ' no evaporation duct height
     del = 0!
ELSE

'    Following terms for NRaD evaporation duct model
     rfac = .04705 * f13
     zfac = .002214 * f13 ^ 2
```

```
    hmin = 1!
    del = delta * zfac
    IF del > 23.3 THEN del = 23.3
    IF del > = 10.25 THEN

'         Duct height greater than or equal to 10.25 meters
          C1 = -.1189 * del + 5.5495
          C3 = 3! / 2!
          C2 = 1.3291 * SIN(.218 * (del - 10!) ^ .77) + .2171 * LOG(del)
          C2 = C2 * 4.72 ^ (-C3)
          C4 = 87! - SQR(313.29 - (del - 25.3) ^ 2)
          zmax = 4! * EXP(-.31 * (del - 10!)) + 6!
          arg = C2 * zmax ^ C3
          slope = 4.72 * C1 * C2 * C3 * SQR(zmax) / TAN(arg)
          C7 = 49.4 * EXP(-.1699 * (del - 10!)) + 30!
          fmax = C1 * LOG(SIN(arg)) + C4 - C7
          C6 = (zmax / 4.72) * slope / fmax
          C5 = fmax / zmax ^ C6
    ELSE

'         Duct height less than 10.25 meters
          C2 = SQR(40623.61 - (del + 4.4961) ^ 2) - 201.0128
          C1 = (-2.2 * EXP(-.244 * del) + 17!) * 4.72 ^ (-C2)
          C4 = SQR(14301.2 - (del + 5.32545) ^ 2) - 119.569
'         The # symbol is Microsoft BASIC double precision notation
          C3 = (-33.9 * EXP(-.5170001# * del) - 3!) * 4.72 ^ (-C4)
          C5 = 41! * EXP(-.41 * del) + 61!
    END IF

    atten = 92.516 - SQR(8608.7593# - (del - 20.2663) ^ 2)
    IF atten < .0009 THEN atten = .0009
    atten = atten * rfac
    IF del < = 3.8 THEN tlm = 216.7 + del * 1.5526
    IF del > 3.8 THEN tlm = 222.6 - (del - 3.8) * 1.1771
    difac = 51.1 + tlm + 4.343 * LOG(rfac)
END IF
END SUB
```

```
SUB difint (opmaxd, opmaxl, r, ff) STATIC

' Process: Calculates 20 times the (base 10) logarithm for the propagation factor
'          within the intermediate region, i.e. for ranges greater than opmaxd and
'          less than rsubd.
' Inputs from common block: fsloss, rsubd, sbdht
' Inputs from argument list: diff, opmaxd, opmaxl, r, sbdloss
' Outputs to common block: None
' Outputs to argument list: ff, r, rsubd
' Subroutines called: dloss, sbd
' Subroutine called by: FFACTR

CALL dloss(rsubd, diff)
diff = diff - fsterm - 8.686 * LOG(rsubd)
deltaf = (r - opmaxd) * (opmaxl - diff) / (opmaxd - rsubd)
ff = opmaxl + deltaf
IF (sbdht > 0!) AND (sbdht >= ht) THEN
     dtemp = ff + fsloss
     CALL sbd(r, sbdloss)
     IF (sbdloss < dtemp) THEN dtemp = sbdloss
     ff = dtemp - fsloss
END IF
END SUB
```

```
SUB dloss (r, diff) STATIC

' Process: Calculate the diffraction region loss
' Inputs from common block: atten, delta, difac, dtot, fsterm, xterm
' Inputs from argument list: r, tloss
' Outputs to common block: None
' Outputs to argument list: diff, r
' Subroutines called: tropo
' Subroutine called by: FFACTR, difint

'     Calculate diffraction region loss using CCIR model
tenlgr = 4.343 * LOG(r)
x = xterm * r
fofx = 11! + 4.343 * LOG(x) - 17.6 * x
diff = dtot + 2 * tenlgr - fofx
IF (delta < > 0!) THEN
      diffe = difac + tenlgr + atten * r
      IF (diffe < diff) THEN

'           Use lesser of CCIR and NRaD evap. duct models
            diff = diffe
      END IF
END IF
diff = diff + exloss
CALL tropo(r, tloss)

'     Add the troposcatter loss to the diffraction loss
dif = diff - tloss
IF (dif > = 18!) THEN
      diff = tloss
ELSEIF (dif > = -18!) THEN
      diff = diff - 4.343 * LOG(1 + EXP(dif / 4.343))
END IF
END SUB
```

```
SUB GetTheta (p$, r1, r, theta, r2) STATIC

' Process: Calculates optical phase-lag difference angle, theta, from reflection
'           point range, r1.
' Inputs from common block: ae2, aeth, h1, h2, h24ae2, r1, thefac
' Inputs from argument list: p$, r1, phi
' Outputs to common block: psi
' Outputs to argument list: p$, psi
' Subroutines called: ref
' Subroutine called by: oplimit, r1iter

h1p = h1 - r1 * r1 / ae2
rkpsi = h1p / r1
psi = .001 * rkpsi
IF psi > .05236 THEN psi = ATN(.001 * h1p / r1)
r2 = (SQR(rkpsi * rkpsi + h24ae2) - rkpsi) * aeth
r = r1 + r2
h2p = h2 - r2 * r2 / ae2
CALL ref(p$, psi, phi, rmag)
theta = phi + thefac * h1p * h2p / r
END SUB
```

```
SUB GOFZ (z, G) STATIC

' Process: Calculate the diffraction region height-gain in dB for the CCIR
'           diffraction region model
' Inputs from common block: capk
' Inputs from argument list: z
' Outputs to common block: None
' Outputs to argument list: G
' Subroutines called: None
' Subroutine called by: dconst

IF z > 2! THEN
     G = 17.6 * SQR(z - 1.1) - 2.1715 * LOG(z - 1.1) - 8!
ELSE
     IF z > 10! * capk THEN
          G = 8.686 * LOG(z + .1 * z * z * z)
     ELSE
          G = 2! + 8.686 * LOG(capk)
          IF z > capk / 10! THEN
               zkfac = .4343 * LOG(z / capk)
               G = G + 9! * zkfac * (zkfac + 1!)
          END IF
     END IF
END IF
END SUB
```

```
SUB hgain (h, fzdb1, fzdb2) STATIC

' Process: Calculates height-gain factor in dB for a specified height
' Inputs from common block: c1, c2, c3, c4, c5, c6, c7, del
'         freq, h, hmin, sbdht, zfac, zmax
' Inputs from argument list: h
' Outputs to common block: None
' Outputs to argument list: fzdb1, fzdb2
' Subroutines called: None
' Subroutine called by: dconst, skipzone


fzdb1 = 0!
fzdb2 = 0!

'     Surface-based duct height-gain factor
IF (sbdht > 0!) THEN
      z1 = h / sbdht
      IF ((freq <= 150!) AND (z1 < .8)) THEN fzdb1 = -60! * (z1 - .5) ^ 2
      IF ((freq <= 150!) AND (z1 >= .8)) THEN
            fzdb1 = 1.14 * z1 ^ (-6.26) - 10!
      END IF
      IF ((freq > 150!) AND (z1 < 1!)) THEN fzdb1 = 10! - 200 * (z1 - .5) ^ 4
      IF ((freq > 150!) AND (freq <= 350!) AND (z1 >= 1!)) THEN
            fzdb1 = 7.5 * z1 ^ (-13.3) - 10!
      END IF
      IF ((freq > 350!) AND (z1 >= 1!)) THEN fzdb1 = 12.5 * z1 ^ (-8!) - 15!
END IF

'     Evaporation duct height-gain factor
IF (del > 0!) THEN
      z2 = h * zfac
      IF (z2 < hmin) THEN z2 = hmin
      IF (del >= 10.25) THEN
            IF (z2 > zmax) THEN
                  fzdb2 = C5 * (z2 ^ C6) + C7
            ELSE
                  fzdb2 = C1 * LOG(SIN(C2 * (z2 ^ C3))) + C4
            END IF
      ELSE
            fzdb2 = (C1 * z2 ^ C2) + (C3 * z2 ^ C4) + C5
      END IF
END IF
END SUB
```

```
SUB opconst STATIC

' Process: Initializes constants for optical region
' Inputs from common block:  antype$, freq, h1, h2, hr, ht
'          humid, polar$, rk, wind
' Outputs to common block:  ac, ae2, aeth, fsterm, h24ae2,
'          hbar, hbfreq, hdif, horizn1, m2imag,
'          m2real, thefac, wvatten
' Subroutines called:  None
' Subroutine called by: FFACTR

'    Variables for reflection coefficient subroutines.  Also used
'    in the diffraction region subroutine.
fsqrd = freq * freq
fcube = freq * fsqrd

eps = 70.0                                   'salt water relative permittivity
IF (freq > 2253.5895) THEN
     a = 1.4114535e-2
     b = -5.2122497e-8
     c = 5.8547829e-11
     d = -7.6717423e-16
     e = 2.9856318e-21
     eps=1./(a + b*freq + c*fsqrd + d*fcube + e*fsqrd*fsqrd)
END IF

sigma = 5.0                                  'salt water conductivity
IF (freq > 1106.207) THEN
     r = 3.8586749
     s = -2.1179295e-5
     t = 9.1253873e-4
     u = 6.5727504e-10
     v = 1.5309921e-8
     w = -1.9647664e-15
     sigma = (r + t*freq + v*fsqrd)
     sigma = sigma/(1. + s*freq + u*fsqrd + w*fcube)
END IF

'    Real & imaginary part of square of index of refraction
m2real = eps
m2imag = (-18000!) * sigma / freq

'    Variables for RUFF subroutine
hbar = .0051 * (.5144 * wind) ^ 2            ' rms wave height
hbfreq = .02094 * freq * hbar                ' (hbar*2*Pi)/wavelength
```

```
'     Variables for miscellaneous subroutines
ae = rk * 6371                                   ' effective earth radius - km
twoae = 2! * ae
aeth = rk * 6.371
ae2 = aeth * 2!
thefac = freq * 4.193E-05                        ' 4*Pi / wavelength
fsterm = 32.45 + 8.686 * LOG(freq)               ' free space loss term

'     CCIR model water vapor attenuation rate constants
freqg = freq / 1000!                             ' frequency in GHz
wv1 = 3.6 / ((freqg - 22.2) ^ 2 + 8.5)
wv2 = 10.6 / ((freqg - 183.3) ^ 2 + 9!)
wv3 = 8.9 / ((freqg - 325.4) ^ 2 + 26.3)

'     water vapor attenuation rate in dB/km
wvatten = (.05 + .0021 * humid + wv1 + wv2 + wv3)
wvatten = wvatten * freqg ^ 2 * humid / 10000!

'     Variables for OPLIMIT subroutine
psilim = .01957 / (rk * freq) ^ (1! / 3!)        ' grazing angle limit
END SUB
```

```
SUB opffac (gamma, range, psi, r1, r2, patd, dr) STATIC

' Process: Calculates parameters used to determine the pattern propagation factor,
'          F, in the optical region. Calculate antenna pattern factor for direct ray,
'          alpha, and reflected ray, beta.
' Inputs from common block: ae, hdif, patfac, patrfac, psi, rmag, twoae
' Inputs from argument list: gamma, patfac, range, r1, r2, ruf
' Outputs to common block: alpha
' Outputs to argument list: alpha, beta, sinpsi, patd, dr
' Subroutines called: antpat, ruf
' Subroutine called by: oplimit, opticf

patfac = 1!
alpha = (hdif / range) - (range / twoae)
sinpsi = SIN(psi)
CALL antpat(alpha, patfac)
patd = patfac
beta = -(gamma + psi)
CALL antpat(beta, patfac)

'    Calculate surface roughness coefficient
CALL ruff(psi, sinpsi, ruf)
divfac = 1! / (SQR(1! + (2! * r1 * r2 / ae) / (range * sinpsi)))
dr = patfac * ruf * divfac * rmag
END SUB
```

```
SUB oplimit (opmaxd, opmaxl, exloss) STATIC

' Process:  Calculates the maximum range, opmaxd, in the optical region and the
'            loss at opmaxd.
' Inputs from common block:  ae, ae2, del, hr, ht, pi, polar$, r1lim, r1min
' Inputs from argument list:  dr, patd, r, r1, r2, theta, thetalim
' Outputs to common block:  exloss, r1lim, r1min
' Outputs to argument list: gamma, opmaxd, opmaxl, polar$, r, r1, r2, thetalim
' Subroutines called: GetTheta, opffac, r1iter
' Subroutine called by:  FFACTR


'    Initial guess for r1 (for wavelength/4 limit based on grazing angle limit, r1lim).
r1 = r1lim

'    theta value at 1/4 wavelength limit, horizontal polarization
rtheta = 1.5 * PI

CALL r1iter("H", rtheta, r1, r2, r)
IF r1lim > r1 THEN r1 = r1lim                    ' grazing angle limit applies
r1lim = r1
IF r1lim < r1min THEN r1min = .5 * r1lim

IF del > 0! THEN
     CALL GetTheta(polar$, r1lim, r, thetalim, r2)
     theta1pk = 2! * PI
     CALL GetTheta(polar$, r1min, r, theta, r2)
     IF theta1pk > theta THEN theta1pk = theta
     IF del < 10.25 THEN
          thetalim = thetalim + del / 10.25 * (theta1pk - thetalim)
     ELSE
          thetalim = theta1pk
     END IF
     CALL r1iter(polar$, thetalim, r1lim, r2, r)
END IF

r1 = r1lim
CALL GetTheta(polar$, r1, r, theta, r2)
IF ht >= hr THEN
     gamma = r2 / ae
ELSE
     gamma = r1 / ae
END IF

CALL opffac(gamma, r, psi, r1, r2, patd, dr)
```

```
fsqrd = patd ^ 2 + dr ^ 2 + (2! * dr * patd * COS(theta))
IF fsqrd < .0000001 THEN fsqrd = .0000001
opmaxd = r
opmaxl = -4.343 * LOG(fsqrd)       ' -20 * LOG10(F)
exloss = -8.686 * LOG(patd)
END SUB
```

```
SUB opticf (r, ff) STATIC

' Process: Calculates the optical path-length difference angle, theta, by solving a
'          cubic equation for the reflection point range, r1.
' Inputs from common block: ae, aeth, ae2, h1, h2, ht, hr, polar$, thefac
' Inputs from argument list: dr, patd, phi, r
' Outputs to common block: psi
' Outputs to argument list: ff, gamma, polar$, psi, r, r1, r2
' Subroutines called: opffac, ref
' Subroutine called by: FFACTR

r1 = (h1 / (h1 + h2)) * r
t = -1.5 * r
v = .5 * r * r - aeth * (h1 + h2)
w = aeth * r * h1
epsr = .05
dd = 2! * epsr
jk = 1
DO WHILE jk < 10 AND ABS(dd) > epsr
     jk = jk + 1
     fr1 = r1 * r1 * r1 + (t * r1 * r1) + (v * r1) + w
     fpr1 = (3! * r1 * r1) + (2! * t * r1) + v
     dd = fr1 / fpr1
     r1 = r1 - dd
     IF r1 < 0! OR r1 > r THEN r1 = r / 2!
LOOP

r2 = r - r1
htp = h1 - r1 * r1 / ae2
hrp = h2 - r2 * r2 / ae2
psi = .001 * htp / r1
CALL ref(polar$, psi, phi, rmag)
theta = (thefac * htp * hrp / r) + phi
IF ht >= hr THEN
     gamma = r2 / ae
ELSE
     gamma = r1 / ae
END IF
CALL opffac(gamma, r, psi, r1, r2, patd, dr)
fsqrd = patd * patd + dr * dr + (2! * dr * patd * COS(theta))
IF fsqrd < .0000001 THEN fsqrd = .0000001
ff = -4.343 * LOG(fsqrd)
END SUB
```

```
SUB r1iter (p$, rtheta, r1, r2, r) STATIC

' Process: Finds reflection point range "r1" corresponding to an angle "rtheta"
' Inputs from common block: horizn1
' Inputs from argument list: f, f1, p$, r, r1, r2, rtheta
' Outputs to common block: None
' Outputs to argument list: p$, r, r1, r2,
' Subroutines called: GetTheta
' Subroutine called by: oplimit

irlmda = 0
dd = r1
DO WHILE ABS(dd) > .001 AND irlmda < 100
     CALL GetTheta(p$, r1, r, f, r2)
     CALL GetTheta(p$, r1 + .001, r, f1, r2)
     fp = (f1 - f) / .001
     IF fp = 0 THEN fp = 1E-08
     dd = (rtheta - f) / fp
     irlmda = irlmda + 1
     IF dd > -r1 THEN
          IF dd + r1 <= horizn1 THEN
               r1 = r1 + dd
          ELSE
               r1 = (r1 + horizn1) / 2!
          END IF
     ELSE
          r1 = r1 / 2!
     END IF
LOOP
END SUB
```

```
SUB ref (p$, psi, phi, rmag) STATIC

' Process: Calculates magnitude, rmag, and phase lag, phi, of the reflection
'          coefficient
' Inputs from common block: PI, m2imag, m2real
' Inputs from argument list: p$, psi
' Outputs to common block: rmag
' Outputs to argument list: phi
' Subroutines called: None
' Subroutine called by: GetTheta, opticf

rmag = 1!
phi = PI
rch = rmag
phih = phi
IF p$ < > "H" THEN
     sinpsi = SIN(psi)
     y = m2imag
     x = m2real - COS(psi) ^ 2
     rmagroot = (x * x + y * v) ^ .25
     angroot = ATN(y / x) / .
     rootreal = rmagroot * COS(angroot)
     rootimag = rmagroot * SIN(angroot)
     at = m2real * sinpsi - rootreal
     ct = m2real * sinpsi + rootreal
     bt = m2imag * sinpsi - rootimag
     dt = m2imag * sinpsi + rootimag
     refvreal = (at * ct + bt * dt) / (ct * ct + dt * dt)
     refvimag = (bt * ct - at * dt) / (ct * ct + dt * dt)
     rcv = SQR(refvreal * refvreal + refvimag * refvimag)

     IF refvreal < > 0! THEN
          phiv = ATN(refvimag / refvreal)
          IF refvreal < 0! THEN phiv = phiv + PI
     ELSE
          IF refvimag < 0! THEN phiv = -PI / 2!
          IF refvimag > 0! THEN phiv = PI / 2!
          IF refvimag = 0! THEN phiv = 0!
     END IF

     phiv = -phiv
     IF phiv < 0! THEN phiv = phiv + 2! * PI
     rmag = rcv
     phi = phiv
```

```
        IF p$ = "C" THEN
            rx = SQR(rch * rch + rcv * rcv + (2! * rcv * rch * COS(phih - phiv)))
            rmag = rx / 2!
            a = rcv * SIN(phiv + phih) / rx
            a = ATN(a / SQR(1! - a * a))
            phi = phih - a
            phi = -phi
            IF phi < 0! THEN phi = phi + 2! * PI
        END IF
    END IF
END SUB
```

```
SUB ruff (psi, sinpsi, ruf) STATIC

' Process:  Calculates the surface-roughness coefficient as a function of grazing angle
'           psi using the Miller/Brown/Vegh approximation from CCIR, Vol V, Rep
'           1008-1.
' Inputs from common block:  hbar, hbfreq
' Inputs from argument list:  psi, sinpsi
' Outputs to common block:  None
' Outputs to argument list:  ruf
' Subroutines called:  None
' Subroutine called by:  opffac

ruf = 1!
IF Hbar < > 0! THEN
      g = hbfreq * 2 * sinpsi
      x = .5 * g * g
      y = 3.2 * x
      s = y * y - 7 * x + 9
      s = y - 2 + SQR(s)
      IF s > 0 THEN ruf = 1 / SQR(s)
END IF
END SUB
```

```
SUB sbd (r, sbdloss) STATIC

' Process:  Calculate surface-based duct loss
' Inputs from common block:  exloss, fofz, rsbd, rsbdloss, sbdht
' Inputs from argument list:  r
' Outputs to common block:  None
' Outputs to argument list:  sbdloss
' Subroutines called:  None
' Subroutine called by:  difint, FFACTR

IF (sbdht = 0!) OR (ht > sbdht) THEN
    sbdloss = 1000!
ELSE
    IF r < rsbd THEN
        sbdloss = rsbdloss + (rsbd - r) + exloss
    ELSE
        sbdloss = fsterm + 8.686 * LOG(r) - fofz + exloss
    END IF
END IF
END SUB
```

```
SUB skipzone (hxmtr, hrcvr) STATIC

' Process: Calculates skip-zone range if a surface-based duct is present and calculates
'          the range to the start of the diffraction region.
' Inputs from common block: ae, fsterm, r1min, sbdht
' Inputs from argument list: fofz
' Outputs to common block: rsbd, rsbdloss, rsubd
' Outputs to argument list: hrcvr
' Subroutines called: hgain
' Subroutine called by: FFACTR

'    Determine the height-gain function for surface-based duct. Note! The variable
'    "DUMMY" contains the height-gain function for an evaporation duct which is
'    not used in this subroutine.

CALL hgain(hrcvr, fofz, DUMMY)
rsbd = 0!
IF hrcvr <= sbdht THEN
    och = .9 * sbdht                        ' trapping layer upper 10% of sbdht
    dmdh = .001 / ae
    delm2 = och * dmdh * 2!
    gtrap = och * dmdh / (.1 * sbdht)
    alpha0 = SQR(delm2)
    ray0 = alpha0 / gtrap                   ' range thru trapping layer

    IF hxmtr <= och THEN
        alphat = SQR(delm2 - (och - hxmtr) * 2! * dmdh)
        ray1 = ray0 + (alpha0 - alphat) / dmdh
    ELSE
        ray1 = SQR(gtrap * 2! * (sbdht - hxmtr)) / gtrap
    END IF

    IF hrcvr <= och THEN
        alphar = SQR(delm2 - (och - hrcvr) * 2! * dmdh)
        ray2 = ray0 + (alpha0 - alphar) / dmdh
    ELSE
        ray2 = SQR(gtrap * 2! * (sbdht - hrcvr)) / gtrap
    END IF
    rsbd = (ray1 + ray2) / 1000!            ' SBD start range, km
    IF rsbd < r1min THEN rsbd = r1min
    rsbdloss = fsterm + 8.686 * LOG(rsbd) - fofz
END IF
END SUB
```

```
SUB tropo (r, tloss) STATIC

' Process: Calculate the troposcatter loss based upon Yeh with frequency-gain factor,
'           h0, from NBS 101
' Inputs from common block: ae, exloss, f3, h1, h14pil, h2
'           h24pil, horizn, rns2, rnsterm, tfac, tsub1, tsub2
' Inputs from argument list: r
' Outputs to argument list: tloss
' Subroutines called: None
' Subroutine called by: dloss

tsub0 = r / ae
ttot = tsub0 - tsub1 - tsub2
zeta = tsub0 / 2! - tsub1 + (ht - hr) / (1000! * r)
chi = tsub0 / 2! - tsub2 + (hr - ht) / (1000! * r)
rsub1 = h14pil * ttot
rsub2 = h24pil * ttot
IF rsub1 < .1 THEN rsub1 = .1
IF rsub2 < .1 THEN rsub2 = .1
s = zeta / chi
IF s > 10! THEN s = 10!
IF s < .1 THEN s = .1
q = rsub2 / (s * rsub1)
IF q > 10! THEN q = 10!
IF q < .1 THEN q = .1
hsub0 = (s * r * ttot) / ((1 + s) * (1 + s))
etas = .5696 * hsub0 * (1 + rnsterm * EXP(-.0000038 * hsub0 ^ 6))
IF etas > 5! THEN etas = 5!
IF etas < .01 THEN etas = .01
csub1 = 16.3 + 13.3 * etas
csub2 = .4 + .16 * etas
h0r1 = csub1 * (rsub1 + csub2) ^ -1.333
h0r2 = csub1 * (rsub2 + csub2) ^ -1.333
h0 = (h0r1 + h0r2) / 2!
delh0 = 1.13 * (.6 - .434 * LOG(etas)) * LOG(s) * LOG(q)
IF delh0 > h0 THEN h0 = 2! * h0 ELSE h0 = h0 + delh0
IF h0 < 0! THEN h0 = 0!
tloss = 114.9 + tfac * (r - horizn) + 4.343 * LOG(r * r * f3) - rns2 + h0
tloss = tloss + exloss
END SUB
```

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The purpose of this document is to introduce the contents and operation of the Engineer's Refractive Effects Prediction System (EREPS), version 3.0. EREPS is a system of indivudual stand-alone IBM/PC-compatible programs that have been designed to assist an engineer in properly assessing electromagnetic (EM) propagation effects of the lower atmosphere on proposed radar, electronic warfare, or communication systems. The EREPS models account for effects from optical interference, diffraction, tropospheric scatter, refraction, evaporation and surface-based ducting, and water-vapor absorption.

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